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ON THE SENSITIVENESS OF THE COHERER

BY

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ON THE SENSITIVENESS OF THE COHERER.¹

INTRODUCTION.

The following investigation is the result of an effort to determine, quantitatively, the effect of electro-magnetic radiation on the coherer.

Although the continual variation of its resistance precludes any exact determinations, the effect of the kind of metal used and of the intervening medium becomes evident when the actual changes of resistance of different coherers under definite conditions is recorded.

Professor Hughes, in 1879, while working with his microphone, noticed that a neighboring spark caused a fall of resistance. Calzecchi Onesti² seems to have noticed a similar phenomenon in 1885, but nothing definite was known till Branly³ published an article in 1890. He observed that when powdered metallic copper was deposited on glass, and this copper placed in circuit with a galvanometer and a Daniell cell, a spark at a neighboring induction coil caused a considerable diminution of resistance. Other metals were tried, iron, aluminium, antimony, tellurium, cadmium, zinc and bismuth, each prepared in a way similar to the copper above mentioned, and in each case, a diminution of resistance was produced; but he found that platinumized glass and peroxide of lead increased in resistance under the same conditions. He noticed also, that a disturbance, such as a slight tap, caused an increase in the resistance of these metal particles, and that an alternating current or a direct current of considerable electro-motive force caused a fall of resistance. He

¹ This paper was prepared as a thesis for the degree of Bachelor of Science, and was awarded the Science Club medal in 1900.

² *Nuovo Cimento*, Jan., 1885; *Beibl.*, IX, p. 433; X, p. 792.

³ *C. R.*, CXI, p. 785; *ibid.*, CXII, p. 90.

also observed that when metal filings were mixed in certain proportions with Canada balsam and the mixture had hardened, the same decrease of resistance was noted.

From these facts Branly advanced the theory that the dielectric separating the metallic particles was in some way changed by the influence of the neighboring spark so that it became conducting.

Nothing more appears to have been done until about four years later, when Professor Lodge,¹ on repeating some of Branly's experiments, advanced the theory that the diminution in resistance was caused by the formation of a metallic bridge through the dielectric, due to a difference of potential between the two sides. He calculated that if two pieces of metal were separated by a film of air .0001 mms. thick, the force of attraction per unit area, due to a potential difference of one volt, would be about 44 atmospheres. He considered the attraction due to such a force sufficient to cause metallic particles to pass through the dielectric, thus building up a metallic connection, which, however, would usually be so unstable that a slight tap would break it down and again increase the resistance. According to this theory, he called these poor contacts "coherers."

This theory received substantial support from the work of Malagoli² and of Arons³. The former succeeded in photographing small sparks between metallic particles, which were being subjected to electro-magnetic radiation, while the latter examined particles under the same conditions with a microscope and observed minute sparks and a movement of the particles.

Tommasina⁴ also obtained evidence for the same theory. He suspended metallic particles in liquids and found that, when the spark of an induction coil was passed through them, the particles united to form chains, in some cases as many as 20 cms. in length. He also showed that the radiation caused an adhering of particles, by suspending a metal ball over a plate of filings in

¹Phil. Mag. XXXVII, p. 94.

²Lond. Electrician, Dec., 1898.

³Wied. Ann. LXIV, p. 567.

⁴C. R. CXXVII, pp. 1014-1092.

circuit with a battery and galvanometer. After the passage of a neighboring electric spark, the circuit conducted, and on lowering the metal filings, he observed very fine metallic threads clinging to the ball.

Auerbach¹, Leppin² and others observed that acoustic, heat, and light waves affected these contacts, though not to such an extent as did the electro-magnetic radiation.

Branly, Dorn,³ and others noticed that oxidized metals responded better than did the clean ones. Neugschwender⁴ found that when a silver-on-glass mirror was placed in an electric circuit and a fine scratch made across the silver so as to make it non-conducting, moisture deposited on the scratch, as by breathing, made it again conducting. Electro-magnetic radiation, however, caused a temporary diminution of the conductivity, the diminution lasting only as long as the radiation continued. He also found that thin layers of electrolytes always showed this increase of resistance, and the phenomenon was later ascribed to polarization. Aschkinass⁵ examined metallic contacts when moist and observed the same phenomenon.

Behrendsen⁶ tried powdered arc carbon and found that, unlike the metals, the radiation did not produce an immediate fall of resistance, but a gradual diminution proportional to the intensity and to the time during which the radiation continued.

Branly had noticed that peroxide of lead increased in resistance, and later Sundorph⁷ examined the same substance and found the peroxide of lead slightly reduced, after it had been subjected to the radiation.

Branly⁸ also had shown that platinized glass increased in resistance; Van Gulick⁹ explained this by saying that sparks

¹Wied. Ann. LXVI, p. 760.

²Ibid. LXV, p. 885.

³Ibid. LXVI, p. 136.

⁴Ibid. LXVII, p. 430; LXVIII, p. 92.

⁵Lond. Elect. XLIII, p. 136.

⁶Wied. Ann. LXVI, p. 1024.

⁷Ibid. LXVIII, p. 594.

⁸C. R. CXII, p. 90.

⁹Wied. Ann. LXVI, p. 136.

were observed in this case and that these might be intense enough to melt down the union.

Aschkinass¹ studied these contacts under various conditions and concluded that results could not be depended upon when the intensity of the spark was considerable, and that then, at least, Lodge's theory held, but that it might not hold when the radiation was weak. He also found that a certain potential difference between two strips of tin foil produced the fall of resistance as did the distant electric spark. He suggested that there might be such critical values of the potential difference for all the metals, and if there were, the one having the lowest critical value, he believed, would be the most sensitive.

One of the most noticeable features of the results already obtained is the scarcity of quantitative data for the different metals. Such quantitative data are due chiefly to Trowbridge² and Guthe and Trowbridge,³ who used single contacts and a varying current density.

It has been found in some preliminary work that when the coherer consisted of but two pieces of metal rather than a mass of particles, and when the source of radiation was several meters from the coherer, much more consistent results could be obtained.

The object of the present research was to determine the amount of change of resistance of single contacts of different metals, under varying conditions, when subjected to comparatively feeble electro-magnetic radiation.

The investigation is divided into three parts. In Part I is recorded the diminution of resistance of coherers composed of the following metals: aluminium, tin, lead, zinc, iron, copper, silver, nickel, platinum, gold. In Part II the effect of establishing various differences of potential between the two pieces of the coherer, by means of a second battery, is shown. In Part III

¹Lond. Elect. XLIII, p. 441.

²Am. Jour. of Science, Sept., 1899.

³Phys. Rev. XI, p. 22.

the action of the coherer is studied when the metals are coated with non-conducting films.

METHODS OF OPERATION.

One of the pieces of metal was attached to a lever which could be adjusted, by means of a micrometer screw, to any distance from the other. This contact was placed in series with a Daniell cell and a galvanometer calibrated to read resistance directly by means of a beam of light moving across a scale. An eight-inch induction coil was placed ten meters away, two brick walls intervening. No vertical wires were used either at the sending or receiving station, and accordingly the radiation was comparatively weak.

In order to record the actual changes of resistance that occurred in such a contact, a method of abbreviation was adopted as follows:

a, indicates an adjustment of the micrometer screw.

s, indicates the passage of a spark at the distant induction coil. The primary circuit of the coil was closed by pulling a cord attached to a switch near it, thus avoiding a metallic connection between the two rooms.

t, indicates a tap on the table on which the coherer rested.

i, indicates "of itself," that is, a change occurred which was not produced by the experimenter.

u, indicates an unstable condition, *i. e.*, a fluctuation of the resistance.

x, indicates "no change."

y, indicates "adjusted with difficulty."

r, indicates that the expression preceding it was repeated as often as is indicated by the succeeding term.

Numerals represent the resistances of the contact in ohms. No attempt was made to read them accurately, since nothing would thus be gained, as it was very unusual for a contact to have exactly the same resistance at different times. The readings given are accurate to within ten per cent. When the resistance is given as infinity, a value greater than 1,000,000 ohms

is meant, and when the resistance is given as zero, less than 5 ohms is meant.

Below is an example of a reading taken and an interpretation:

a to 500—s to 0—i to 1000—s to 0—t to 1000—s to 0—sx
—a to u 250—s to 0, etc.

This indicates that the contact was adjusted to a resistance of 500 ohms; that a spark from the induction coil caused a fall to zero; that the resistance returned of itself to 1000 ohms; that another spark caused a fall to zero; that a tap caused an increase to 1000; that another spark caused a fall to zero; that a spark had no effect on the resistance, which was then adjusted to about 250 ohms; that a spark caused a fall to zero, and so on.

PART I.

EFFECT OF ELECTRO-MAGNETIC RADIATION ON SOME OF THE COMMON METALS.

As a basis for comparison, the change of resistance of ten metals was recorded while being alternately subjected to radiation and to tapping.

The metals were examined first in the same condition as obtained, that is, without cleaning, and later, some were tested after being carefully sandpapered; but unless otherwise stated they were in the former condition. Several different contacts of the same kind of metal were tried and the results given are those typical of the metal. After the effects of radiation and tapping were recorded, the resistances to which each contact could be adjusted were determined.

TABLE I.

ALUMINIUM.		
Readings.		Interpretations.
ay to inf.—s to 0—(t to inf., s to 0) r indefinitely.		At first the contact did not respond well; but after it had been used for some time, a tap caused an increase of resistance to infinity and a spark caused a fall to zero. This action was kept up indefinitely.

TIN.

ay to inf.—s to 0—i to inf.—sx—ay to inf.—s to 0—i to inf.—sx—a to inf.—sx—a to inf.—s to 0—i to inf.—sx—t to inf.—s to 0—(to to inf., s to 0) r six times—sx—a to 200—s to 0—(t to inf., s to 0) r five times—sx—(t to inf., s to 0) r seven times—sx—and so on.

The resistance could not be adjusted to values between 250 ohms and infinity.

The adjustment was more difficult than in the above case and the contact did not remain sensitive as long.

The resistance could not be adjusted to values between 250 ohms and infinity.

IRON.

ay to 500—s to 0—1 to 100000—s to 0—i to 100—s to 0—a to u 300—s to 0—t to 200—s to 0—t to 250—s to 0—t to 100—s to 0—t to 200—s to 0—tx—a to 1000—s to 0—t to 2000—s to 0—t to 1000—s to 0—t to 400—s to 0—t to 30—s to 0—tx—a to u 500—s to 0—tx—a to inf.—s to 0—t to 300—s to 0—a to inf.—s to 0—t to 700—s to 0—t to 1100—s to 0—t to inf.—s to 0—and so on, usually tapping back to less than 1000 ohms.

The resistance tapped back sometimes to a high and sometimes to a low value, and could be adjusted to values less than 1500 ohms, otherwise the action was very similar to that of tin.

ZINC.

(a)
ay to 50—i to inf.—s to 0—t to 800—s to 0—t to 300—s to 0—t to 2000—s to 0—t to 900—s to 0—t to 1000—s to 0—t to 900—s to 0—t to 1000—s to 0—and so on, usually tapping back to less than 1100 ohms.

(b) Surfaces cleaned.

ay to inf.—s to 0—tx—ay to inf.—s to 0—t to inf.—s to 0—tx—ay to inf.—s to 0—tx—and so on.

The action was very regular, more like that of aluminium, except that the resistance usually tapped back to less than 1100 ohms.

In the second series will be noticed the effect of clean surfaces, that is, the adjustment was very difficult to make and the contact did not remain sensitive.

TABLE I — continued.

Readings.	LEAD.	Interpretations.
(a) ay to u 300—s to 0—t to inf.—s to 0—t to 100—s to 0—tx—a to 300—s to 0—i to 100—s to 0—tx—a to inf.—s to 0—i to 250—s to 0. (b) Thick coating of foreign substances, oxides, etc., on the surfaces. ay to inf.—s to 0—tx—(ay to inf., s to 0, tx) r indefinitely. (c) Surfaces cleaned. ay to inf.—s to 0—tx—(ay to inf., s to 0—tx) r indefinitely.		The action was very much like that of zinc, except that the resistance did not tap back usually to more than 300 ohms. In (b) is shown the effect of considerable non-conducting substance on the surface; that is, the resistance tapped back to infinity. In (c) is again shown the effect of clean surfaces. The adjustment was difficult and the sensitiveness only momentary.

NICKEL.

ay to inf.—s to 0—i to 4000—s to 0—t to inf.—sx—a to 100000—s to inf.—i to 0—t to inf.—sx—a to 0—t to 100—s to 0—t to 80—s to 0—and so on; the resistance tapping back, usually, to small values.	The resistance was unsteady, tapping back sometimes to high and sometimes to low values, usually, to not more than 100 ohms.
--	---

COPPER.

(a) a to u 100—s to 0—t to 100—s to 0—tx—a to inf.—s to 0—t to 300—s to 0—t to 1000—s to 0—t to inf.—s to 0—t to u 4000—s to 0—t to inf.—i to 1000—s to 0—(t to inf., s to 0) r six times—tx—and so on. (b) Surfaces cleaned. No readings were obtained, the adjustments were so difficult.	The resistance tapped back to nearly all values, and was very unsteady. When the contact was left to itself, the resistance sometimes oscillated back and forth from a high to a low value for fully ten minutes, finally stopping either at infinity or zero.
--	---

SILVER.

ay to inf.—s to 0—t to inf.—s to 0—tx—ay to inf.—s to 0—tx—ay to inf.—s to 0—(ay to inf., s to 0) r indefinitely.	The adjustment was difficult, and the contact did not remain sensitive.
--	--

With gold and platinum contacts the adjustment was so difficult no results were obtained.

The preceding data show that in each case the radiation caused a fall of resistance to about zero from all values less than infinity; and even from that value, if the contact was properly adjusted, that is, if the two pieces of metal were very close together, yet not touching.

A tap caused an increase in resistance, the amount of increase depending, to some extent, on the metal used. Aluminium and tin tapped back to an infinite resistance. Copper tapped back to almost any resistance, while iron, zinc, lead and nickel tapped back, usually, to resistances less than 1000 ohms.

The effect of clean surfaces is also shown in Table I. With such surfaces the adjustment was, in each case, very difficult, and the contact did not remain sensitive.

In some cases, especially with copper, the resistance varied through wide limits, when the contact was left to itself after having been carefully adjusted. The spot of light from the galvanometer moved back and forth, wavering for a time about a certain resistance, then changing suddenly to another, stopping finally either at infinity or at zero.

PART II.

CRITICAL POTENTIAL DIFFERENCES.

Guthe and Trowbridge¹ have shown that there are certain critical values of the applied E. M. F., that is, as the current through the contact was increased, the fall of potential across the terminals of the coherer approached a maximum, usually a fraction of a volt. They noticed also that this value increased with time, that is, as the surfaces became coated with oxides.

The following measurements were taken by the writer to determine these values when the metals are in their ordinary condition instead of when clean. A potential difference of .001 volt was maintained across the terminals of the contact. The

¹ Phys. Rev. XI, p. 22.

distance between the two pieces of metal was adjusted so that it would respond to the distant spark. The contact was then thrown out of that circuit and into one which would give any desired drop across the terminals by means of a potentiometer. It was then thrown back into the first circuit and the change of resistance noted. If there was no change, the contact was tested by the distant spark to be sure that it had remained sensitive. This is not, however, the method that is used by the above authors. Instead of starting at low values and coming up to the critical value by changing the current as they did, the method used here was to determine the least value which would produce the fall of resistance.

TABLE II.

Metal.	Critical Potential Difference.	Remarks.
Aluminium....	2 volts cohered it. 1 volt did not.	The resistance was tapped back to infinity.
Tin.....	3 volts cohered it usually. 2 volts sometimes. 1 volt did not	The resistance was tapped back to infinity.
Iron.....	1 volt cohered it. .7 volts at times. .5 volts did not.	The resistance was tapped back to between 2,000 ohms and zero.
Zinc.....	1 volt cohered it, usually. .5 volts did not.	The resistance was tapped back about as above.
Lead.....	.5 volts cohered it almost always. .2 volts rarely.	The resistance was tapped back to between 500 ohms and zero.
Nickel.....	.3 volts cohered it, usually. .1 volt rarely.	The resistance was tapped back, usually, to less than 100 ohms.
Copper.....	No definite results were obtained.	The resistance was tapped back to many different values and the action was so irregular no results were obtained.

For silver, platinum and gold no results were obtained, because of the difficulty in maintaining the sensitive condition.

It will be seen from the preceding table that the metal which

has the lowest critical potential difference, that is, nickel, tapped back to the lowest resistance, and, in general, the critical potential difference increased as the resistance increased.

In the first investigation lead and nickel did not give very constant results, the resistance of the contacts was unsteady, and the tapping back was irregular; but in the above investigation where a potential difference of .001 volts instead of one volt was used the response was much more regular. Even gold and platinum responded well at times. It was thought that possibly the reason the gold and platinum contacts responded better when .001 volts instead of one volt potential difference was used was, that the latter was above the critical value. To test this for a metal of known potential difference a potential difference greater than two volts (the critical value) was established between the pieces of an aluminium contact, and it was found that the contact responded fairly well until about ten volts was tried. At and above this value taps were not as effective and sometimes the radiation caused an increase of resistance. This appears to be the maximum potential difference at which regular results can be obtained. Other metals were found to have such values but they have not, as yet, been definitely determined.

With the low potential difference .001 volt all the metals responded well, unless the intensity of the radiation was diminished, whereupon a greater potential difference had to be established between the two pieces of the contact before a response could be obtained.

The radiation, in order to be effective, must produce, with the help of the circuit, a potential difference at the contact equivalent to the critical potential difference. For instance, if the intensity of the radiation be such that it produces at the contact an effect equivalent to a potential difference of one volt of a direct current, and the critical voltage of that contact be two volts, then the potential difference at the contact due to the current in the primary circuit must be made equal to one volt before the fall of resistance can be produced. This is undoubtedly the reason that when the oscillator and the receiver in "wireless" tele-

raphy are close together, but one cell is needed in circuit with the coherer, whereas, at greater distances more cells must be added.

It will be seen from the data in Table II that sometimes the resistance of a lead contact tapped back to infinity. In that case the previously found critical potential difference no longer held, but instead, the critical potential difference was found to be about three volts.

The reason no more exact critical potential differences for the different metals could be obtained was, that the resistance did not tap back twice in succession to exactly the same value, though in most cases this variation lay within narrow limits. No critical value was found for copper, probably, because it returned to many different resistances and did not long remain sensitive.

The addition of the current from the second circuit seemed to disturb the sensitiveness to a considerable extent, for though a contact might respond indefinitely to alternate sparks and taps, yet, after the current from the second circuit was added, considerable adjustment was often required before the sensitive condition could again be established. It appears from these facts that the critical potential difference is a function of the resistance to which the contact taps back.

PART III.

THE ACTION OF DIFFERENT METALLIC CONTACTS HAVING SIMILAR SURFACE COATINGS.

It has been shown (page 11) that the action of a metallic contact depends on the condition of the surface; that is, whether it is clean or not. Each metal, in its natural state, has an individual coating on its surface, in most cases, its oxide; hence, in order to compare the difference in the action of the metals themselves, all should be covered with similar coatings. This was done by cleaning the metal with sand paper and dipping it in a

collodion solution. After the ether and alcohol had evaporated, the metal was covered with a thin film whose thickness depended on the concentration of the solution.

Two pieces of the same kind of metal, thus treated, were arranged in the apparatus as described on page 7 and the following results were obtained:

TABLE III.

Readings.	ALUMINIUM.	Interpretations.
ay to inf.—s to 0—(t to inf., s to 0) r ten times—sx—i to 0—t to inf.—s to 0—t to inf.—s to 0—(t to inf., s to 0) r indefinitely.		The adjustment was easy and the response regular. The resistance could be tapped back readily either to infinity or to less than 250 ohms, but a resistance between those two limits was exceedingly difficult to obtain, either by tapping back or by adjusting.
	LEAD.	
a to inf.—s to 0—t to inf.—s to 0—t to inf.—sx—i to 0—t to inf.—sx—a to inf.—s to 0—t to inf.—s to 0—t to inf.—sx—i to 0—t to inf.—s to 0—t to inf.—s to 0—t to inf.—sx—so on irregularly for about five minutes—a to inf.—s to 0—(t to inf., s to 0) r indefinitely.		The action was very similar to that of aluminium, except that it did not become regular till after the contact had been used some time. The resistance was adjusted easily to infinity or to values less than 250 ohms, but only once out of many trials was a resistance between these values obtained.
	IRON.	
a to u 200—s to 0—t to inf.—sx—t to 0—t to 100—s to 0—t to inf.—sx—a to u 200—s to 0—t to u 200—s to 0—t to inf.—s to 0—t to inf.—sx—and so on, irregularly for some time—a to inf.—s to 0—(t to inf., s to 0) r twenty-three times. By careful adjustments, resistances less than 250 ohms could be obtained.		The action was similar to that of lead except that when the resistance was adjusted to values between 250 ohms and infinity, it often fluctuated for a long time, finally stopping at either infinity or less than 250 ohms, and the contact did not remain sensitive.
	ZINC.	
a to inf.—s to 0—tx—a to inf.—s to 0—t to inf.—sx—a to 0—t to inf.—s to 0—t to u 300—s to 0—(t to inf., s to 0) r indefinitely. By careful adjustments, resistances less than 250 ohms could be obtained.		At first the contact did not respond regularly: but after it had been used some time a spark caused a fall of resistance to zero and a tap caused an increase to infinity, as with the metals above. The resistance could be adjusted only to values less than 250 ohms; above that value it fluctuated, as in the case of the iron contact.

TABLE III—continued.

COPPER.		
Readings.		Interpretations.
ay to inf.—s to 0—t to 100—s to 0—t to inf.—sx—ay to inf.—s to 0—t to inf.—s to 0—t to inf.—s to 0—tx—a to 50—s to 0—and so on, irregularly, for some time—a to inf.—s (t to inf., s to 0) r seven times—sx—a to inf.—s to 0—(t to inf., s to 0) r twenty times.		The adjustment was more difficult than in any of the other cases and the contact did not remain sensitive as long. The resistance was always unstable above 250 ohms and sometimes even below that value.
GOLD.		
ay to inf.—s to 0—t to inf.—sx—a to inf.—s to 0—(t to inf., s to 0) r eight times—sx—ay to inf.—s to 0—(t to inf., s to 0) r four times.		The contact was difficult to adjust and did not long remain sensitive. Resistances greater than 250 ohms and less than infinity were not obtained.

Very similar results were obtained on coating the metals with gutta percha, celluloid in ether, shellac, etc.

It will be seen from the foregoing data that in each case the resistance tapped back to infinity or to less than 250 ohms and only rarely could it be adjusted to intermediate values. Though all of these metals showed a uniformity in tapping back, under these conditions and, consequently, the same critical voltage, there were indications of properties peculiar to each; for instance, aluminium responded with the same regularity as when its surface was in the ordinary condition, copper showed the usual unsteadiness, and gold its characteristic inconstancy, that is, the same tendency to lose its sensitiveness.

SUMMARY.

1. It is shown in Table I. that the maximum value below infinity to which the resistance tapped back was not the same for all metals in their ordinary condition; that is, covered by their natural oxides, and that even for the same metal the value differs according to the thickness of this coating (at least in the cases of lead, zinc and copper), while in Table III. it is shown that when the metals were covered with the same substance (colloidion) the limiting value to which the resistance tapped back

was in all cases the same; that is, 250 ohms. But even then the action, in other respects, was not the same for every metal,—aluminium responded with its usual regularity and adjusted readily, whereas gold and platinum were much more difficult to work with.

Therefore, it is concluded that the phenomenon of the change of resistance of poor electrical contacts when subjected to electro-magnetic radiation is a function *both* of the metals themselves and of the intervening medium.

2. It may be seen from Table II. that the critical potentials depend on the resistance to which the contact tapped back, and since the latter depends on the quality as well as the quantity of the surface coating, the critical potential is a function of the intervening medium.

Guthe and Trowbridge¹ showed that different metals had different critical potentials when the surfaces of the metal were clean. Here it is shown that this value varies as the intervening medium varies and in each case this critical value is higher than the value given by them for the clean metal.

3. As stated on page 13, there appears to be a maximum critical potential, that is, one above which the contact ceases to respond with its accustomed regularity.

4. The data from Table III. explain in part why gold and platinum do not respond as well as the other metals. Ordinarily their surfaces are too clean. With a film of collodion between them much better results were obtained. As stated on page 13, both gold and platinum worked better when there was a potential difference of only .001 volts between the two pieces of the contact. It is probable that the resistance of the surface coatings of these metals was so low that the potential difference was above the maximum potential difference, thus giving results similar to those with aluminium, when a potential difference of ten volts was established at the contact.

There appears to be no doubt but that Lodge's theory of the formation of metallic bridges holds when the intensity of the

¹Phys. Rev., XI, p. 22.

radiation is great, for the induced sparks have been seen between the particles, and it is a well known fact that when sparks are passed through a mass of metallic particles, cohering takes place. The question is, Does the same thing happen when the intensity of radiation is very weak?

As already stated, Branly attempted to explain the phenomena by supposing that there was a change of conductivity of the dielectric separating the metals, while in March, 1900, Bose advanced a third theory. He assumes that there is an allotropic change of the metallic surface caused by the radiation. It is known that the red mercuric iodide can be changed into the yellow mercuric iodide by heat, and that the yellow form can be changed back into the red by friction, and he holds that the radiation and the tapping back produce similar changes in the surface of the metal, which is indicated by a change of conductivity.

Guthe and Trowbridge¹ have still another theory. They point out the analogy between the behavior of the coherer and the electrolytic cell. They assume, in common with Lodge that the potential gradient across the coherer causes an attraction of the electrode to within molecular distances over a small area. When the potential gradient exceeds a certain value, a current commences to flow due to metal ions bridging over the space between the electrodes.

They make the arbitrary assumption that a certain definite number of ions are needed to carry a given current without heating. If a larger current be sent through the circuit, then more ions bridge over exterior to the definite area of contact for the given potential gradient.

Granting this, the authors deduce the relation $p = P(1 - e^{-ki})$, where p is the fall of potential across the coherer corresponding to a given current strength i , P the maximum value attained by p , and k a constant depending on the nature of the electrodes. Their experimental data are satisfied by this equation. P is the critical voltage for the given metal when its sur-

¹Phys. Rev., Vol. XI, p. 22.

faces are clean; that is, if a circuit consisting of a cell, coherer and galvanometer be formed, no current will flow if the E. M. F. of the cell is less than P.

Below is a comparison of the phenomena and the theories:

PHENOMENON.	THEORY.			
	<i>Branly.</i>	<i>Lodge.</i>	<i>Bose.</i>	<i>Guthe and Trowbridge.</i>
Decrease of resistance by spark	Agrees.	Agrees.	Agrees.	Agrees.
Increase of resistance by tap.	Agrees.	Agrees.	Agrees.	Agrees.
Increase of resistance by spark.	Admissable.	Admissable.	Admissable.	Admissable.
Decrease of resistance by tap.	Admissable.	Admissable.	Admissable.	Admissable.
Resistance to which a contact taps back depends on intervening medium.	Agrees.	Admissable.	Disagrees.	Agrees.
Different results obtained with different metals when the intervening medium is the same.	Disagrees.	Admissable.	Agrees.	Agrees.
Critical potentials.	Disagrees.	Admissable.	Disagrees.	Agrees.
Gold and platinum respond better with surface coatings.	Agrees.	Admissable.	Disagrees.	Agrees.

It will be seen from the above comparison that Guthe and Trowbridge's theory explains more phenomena than the others, and yet, it is possible that all four theories contain some truth. If such is the case it is not surprising that the phenomena of poor electrical contacts are complicated.

It will be seen from the preceding data that of all the metals tried, aluminium is the most regular in response. It has been found, however, by Marconi and others that nickel gives the best results at long distances. This is probably due to the fact, that of all metals tried, the surface coating of nickel shows the lowest critical potential, that is, it responds to the least energy, as is shown in Table II.: but when the intensity of the radiation is

sufficient to overcome the greater critical potential of aluminium, the latter gives better results than nickel, for the regularity of response has been shown to depend upon the metal itself.

Accordingly, it appears that the best results would be obtained by using the metal which shows the greatest regularity of response, coated with a medium which gives the lowest critical potential.

Physical Laboratory,

University of Wisconsin, Dec., 1901.

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FROM THE BORDERLAND BETWEEN CRYSTALLO- GRAPHY AND CHEMISTRY

BY

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AN ADDRESS DELIVERED BEFORE THE SCIENCE CLUB OF THE
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MARCH, 1904

FROM THE BORDERLAND BETWEEN CRYSTALLOGRAPHY AND CHEMISTRY.

An address delivered before the Science Club of the University of Wisconsin at Madison, October 5, 1903.

Mr. President, Ladies, and Gentlemen:

You have done me the honor of asking me to speak before the Science Club of your flourishing University. I consider this request as a special act of kindness, and a distinction which I owe to the recommendation of my esteemed friend, Professor Hobbs. It is one of the many kindnesses which I have experienced in Madison, for all of which I wish to express my hearty thanks.

You are assembled here in large numbers, probably with the expectation of hearing something interesting. I fear, however, that you may be disappointed, for I doubt my ability to express what I wish to say in English, a language in which I am by no means proficient. I therefore beg of you to accept the will for the deed.

I should like to speak to you about researches and problems at present seriously engaging my attention. These are problems pertaining to the borderland between crystallography and chemistry. They treat of etch-figures and dissolution-forms, and of the methods by which, from these remarkable formations in the region of crystallography, conclusions can be drawn regarding the *structure of crystals* and the *mechanism of the process of dissolution*.

NOTE.—The reader unfamiliar with the advances in crystallography would hardly suspect from Professor Goldschmidt's modest exposition of his theme, to how large an extent he is personally responsible for the changes and extensions which have transformed the science during the last twelve years. He is not only the inventor of the two-circle goniometer and the gnomonic projection in its applications to the science, but the discoverer of the *Law of complication*. The application of this law to musical harmony he has treated in a work entitled *Ueber Harmonie und Complication*, published in Berlin by Julius Springer in 1901.—ED.

In order to make my remarks intelligible, a few words regarding the *method of investigation*, and also of *presentation*, are necessary.

Crystals are measured in the following way: in the simplest case the crystal is supposed to be bounded by plane faces. In such a case the problem is to ascertain the mutual directions of these faces, or, what is the same thing, the mutual directions of the lines perpendicular to these faces. The lines we call *normals*, and these normals form a bundle of rays from a point within the crystal, viz.: the centre. Every ray gives the direction of a face. The bundle represents the crystal with all its faces. The comprehension of all these rays in space is not an easy matter. Therefore, to make their relations more clear, we represent them by their points of penetration through a globe constructed about their centre. Thus every ray is marked on the globe by a point which represents at the same time the corresponding crystal face. We call this point the *face-point*. The representation we call *spherical projection*. Our crystal now appears as a system of points on the globe, there being as many points as the crystal has faces. For comparison let us take the cities on a terrestrial, or the stars on a celestial globe. Since we do not know their distance, the fixed stars are, at the present time, nothing but directions, rays from a point, the stand-point of the observer,—that is, the earth.

Just as we determine the position of a place upon the earth, so do we determine the position of a face, that is, its point upon the sphere by two co-ordinate angles; first, the distance from a pole, and second, the distance from a suitably chosen first meridian. We call these two angles *position angles*, and mark them by the Greek letters ϕ and ρ . In the case of the earth and the sky, the pole is determined by the axial revolution, the first meridian is arbitrary. In the case of crystals other considerations determine the suitable choice of pole and first meridian. For example, with the well known rock crystal the pole is regarded as passing through the apex, and the first meridian as passing through the apex and a line from the centre perpendicular to one of the six prismatic faces. Crystal measurement now consists in fixing the position of the faces, i. e., in measuring this angle, ϕ , which is equivalent to geographical longitude, and the angle ρ ,

which is equivalent to geographical latitude, though measured from the pole instead of the equator. Formerly it was always customary to measure from face to face the angular inclination. This corresponds to *triangulation* in measuring the earth. The instruments employed in measuring crystals are called goniometers. In contradistinction to those before employed exclusively, the modern ones are called two-circle goniometers. Like astronomical instruments, they have two circles, upon which the angles ϕ and ρ can be read when a face (a reflected ray of light from the face) is properly adjusted.

The introduction of the two-circle goniometer has very materially increased our working capacity, and has placed us in a position to measure complicated bodies which formerly did not admit of measurement: for example, bodies with curved faces. Spherical projection, that is, representation on a sphere, did good service in impressing upon the understanding the mutual relationships of the faces of these bodies. Another method of representing our rays or normals, a method called *gnomonic projection*, has proved to be of still greater service. In this method the rays (face-normals) are received on a *plane* instead of on a sphere. For crystals this is of material advantage, for it is a fundamental peculiarity of crystals, that their faces are arranged in zones, i. e., in series of faces with parallel edges, or, what means the same, the points representing the faces of a crystal in gnomonic projection, *zone-lines*. This is just as if on the earth's surface the cities should be situated exactly on the equator or on several selected meridians or great circles.

Further, in *gnomonic projection* the wonderful property peculiar to crystals is shown, viz. that the face-points of any crystal species, for example, of calcite, are not only arranged in rows, but also that the distances between points in each row (zone-line) follow a simple number-law. Fig. 1 shows such a case. We see in the picture strikingly favored points (*chief-knots*), between which the point-rows (zones) extend. The chief-knots give the position of the chief faces. We note that the zones radiate from the chief-knots, and if we make measurements in the cut with a pair of compasses, we find that there is a unit measure (element with which we can rationally measure all the distances in the favored zones)—that is, to indicate the positions

of the faces simple whole numbers or fractions of this element suffice, such as 0, 1, 2, 3, $\frac{1}{2}$, $\frac{2}{3}$, π . Every two of these numbers (*coordinates pq.*) define the position of the face just as well as the angular position does. We call these two combined letters the symbol of the face.

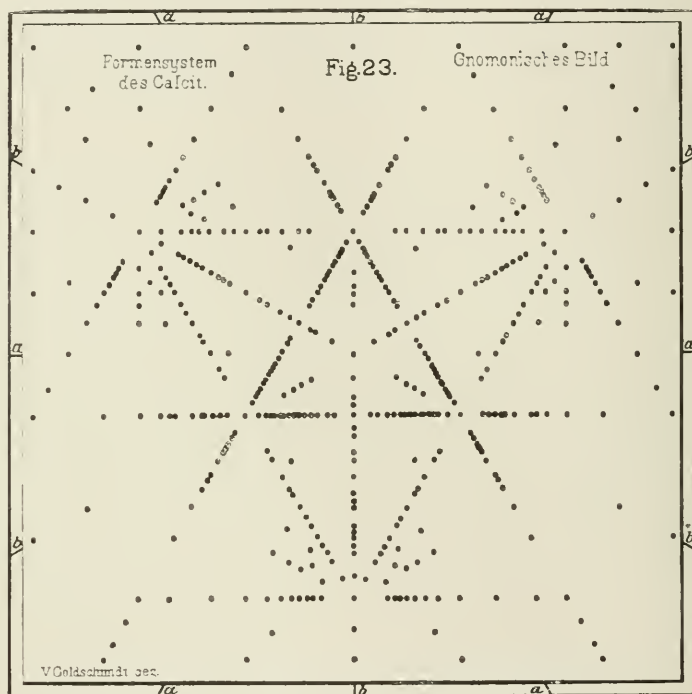


FIG. 1.

Genetically the *chief-knots* and *chief-zones* play an important part. We consider that they indicate the location, or rather the direction, of the *particle-forces*; that is of the cohesive-forces with which the particles building up the crystal attract one another, with which they hold each other firmly together, with which they bind each other together at equal distances in rows and planes and so make up the structure which we call a crystal. This crystal is enclosed by faces, which are often plane faces.

In a similar manner a building is constructed of dressed stone or brick. The walls of the structure follow the same directions

as the sides of the bricks. Likewise the crystal faces are perpendicular to the attractive forces of all the particles forming the crystal, which we assume lie parallel to one another, or as we say, similarly oriented. The *face-normals* are at the same time the *particle-forces*. These interest us according to their intensity and direction in all genetic questions like the following. How does the crystal with its faces and its remarkable physical properties develop? How does it grow? How is it dissolved—how does it resolve itself into its molecules? What kind of forces are active there and how do they act? These are the questions that occupy our attention.

Still another noteworthy fact may perhaps be mentioned. Let us now measure in the gnomonic picture of all the forms observed in a crystal series, say of calcite (Fig. 1), the distance of all the points between chief-knot and chief-knot and write them down. Then a simple number-law is seen, which holds good not only in certain zones and knots but in all zones. This is true not only in the case of calcite, but in the case of all sorts of crystals in the entire domain of crystallography. This simple numerical law goes by the name of the law of *complication*. It gives the following number scheme:

$$\begin{array}{rcccccccccc}
 N_0 & = & 0 & . & . & . & . & . & . & \infty \\
 N_1 & = & 0 & . & . & . & I & . & . & \infty \\
 N_2 & = & 0 & . & 1_2 & . & I & . & 2 & \infty \\
 N_3 & = & 0 & 1_3 & 1_2 & 2_3 & I & 3_2 & 2 & 3 & \infty
 \end{array}$$

and so forth.

This number scheme is constantly repeated. The comprehension of this enables us to see into the development of crystal forms. We call the different rows of this number scheme *normal series* or *harmonic series*. Wonderful to relate, this same numerical law occurs in the sounds composing our musical system; sounds forming the works of our great masters, the harmony of which so delights our ears: for a simple transformation of the series of figures representing the relative numbers of harmonic sounds makes our harmonic series apparent. It is the same transformation which must be applied, also, in many cases to the figures of crystal forms to make the harmonic series appear.

A closer study of the logical consequences of this law of com-

plication enabled us to develop an analysis of musical works—an analysis which discloses their harmonic construction and shows which rules Beethoven, Bach, Palestrina and the other composers, when producing their masterpieces, unconsciously followed under the constraint of the laws of nature.

If now we return to the measuring of crystals, we find that the two-circle goniometer has made it possible for us to measure not only plane faces but also curved ones. Every plane face gives as a reflection a point of light on the instrument, a point in the projection-picture on the globe or in the gnomonic plane. This point corresponds to the position of the face.

A curved face, the direction of which varies at every point, gives as a reflection on the instrument, a streak of light—a *light-path*. When this light-path is reproduced in the gnomonic projection-picture it appears as a constant succession of points, as a line either straight or curving. These lines give a representation of the position and curvature of the face. It soon becomes evident that the plane faces, which up to this time have been exclusively the object of measurement, are only special cases; or, speaking mathematically, that crystal-faces in general are curved, and that in these curves a wonderful regularity and obedience to law are seen. This opens up a wide field of research and shows the paths of creative Nature. But this is just what we want to know. We try to follow Nature on her creative pathways.

We said that the position (projection-points) of the chief-faces (chief-knots) according to our assumption denote the direction of the particle-forces which form the crystal. Now the measurement of the curved faces shows that the streaks of reflected light, the light-paths, from the curves always extend from one chief-knot to another. They are the directions in which the primary forces of the particle cooperate. The curves in the projection-picture correspond to imperfectly developed, that is undifferentiated, zones. But from experience we know that when differentiation occurs,—when plane faces are formed—the arrangement of those faces is in accord with the law of *complication*, the same law in obedience to which the vibrating chord produces its harmonious nodes (knots).

From the chief-knots the chief-zones radiate, and if we wish to detect only these chief-knots, the curves suffice: indeed, the

curves mean more to us than the points denoting the plane faces. In order to point out the connection of the crystal forms and the particle forces (which we consider perpendicular to the crystal faces), to the internal structure of the crystal building particles, we require another hypothesis. For this purpose let us consider that the particles (or in one of our illustrations, the building-stones), by the parallel orientation of which the crystals are constructed, consist of a limited number of molecules. Let these be in a definite order and firmly united in the particle. This union is the subject of study of stereo-chemistry. Each particle has its centre of gravity; in like manner every single molecule composing it has its centre of gravity. We assume now, till we learn better, that the directions of the particle-forces proceed from the centre of gravity of the particle through the centres of gravity of the individual molecules (in some cases of the atoms).

On the basis of this hypothesis a cooperation of crystallography and chemistry can be inaugurated. Crystallography gives by measurement of the crystals the direction of the particle-forces perpendicular to the chief faces. Chemistry furnishes us with knowledge of the molecules. Both branches of science have the same object in view and will some day be joined.

Two sorts of curved faces of crystals engage our special attention: the first due to the growth of the crystal, the second due to dissolution. In the first case we speak of crystal faces and growth figures: in the second case of etch-figures, dissolution-faces, and dissolution-forms. We may as well call the latter *decreasing forms* or *forms of decrection*. On the one hand we have to do with the forms of construction, on the other with those of destruction.

In the case of the forms due to the constructive action of the particles, we can trace in their curved reflections, the light-paths,—the action of the particle-forces when the crystal is being built. Those curved faces with their most characteristic features are historical monuments in the history of crystal-building. Nature has preserved them for us in millions. In comparison with them the monuments of human history are few in number.

The *etch-figures* and *dissolution-forms*, on the contrary, show in their curved light-paths determined by measurement, the his-

torical method followed by the process of dissolution. They show the direction and the manner of co-operation of the aggressive and defensive forces in the act of destruction. In this manner they give us a foundation for a theory of the *mechanics* of the dissolution process.

This theory of dissolution, just as well as the mechanical theory of crystal growth, interests the physicist and chemist, as much as it does the crystallographer. It also interests the biologist and the geologist. For all creation and decay in Nature is a process of construction and destruction, and we can say that the solution of this problem in its most elementary form belongs to the domain of crystallography; and this task, with all that pertains to it, assigns crystallography, to a central place among the sciences, whose task it is to give to the human mind an insight into creative Nature's working.

Now let us first briefly examine the *etch-figures*. These are small elevations and excavations—hills and hollows—which are brought out when a crystal face is acted upon for a time by a solvent; for example, calcite (CaCO_3) treated with hydrochloric acid (HCl). Widmannstätten in Vienna in 1808 was the first to call attention to this. He etched the surfaces of meteoric iron and showed that the structure of these wonderful visitors to earth from the sky can be recognized by means of the etch-figures, and distinguished from that of telluric iron. At present a development of this method of research is technically employed in the study of the composition and structure of the many varieties of iron and steel, as well as of alloys which the metal industry furnishes.

In the case of crystals it becomes evident that the etch-figures gave us the means of recognizing the crystal system as well as hemihedrism and twinning in many cases in which other means failed. For this purpose, small as they are, they were studied under the microscope and reproduced by micro-photography. An essential step in advance in the comprehension of the study of the etch-figures was made by the two-circle measurement. Thereby it was found that these hills and hollows produced by etching are bounded by curved faces. The light-path of these, observed and measured by the goniometer and transferred to the projection-picture, showed a system of lines and knots which

was proven to be identical with the lines and knots representing the form system of the crystal species examined.

Hence we have in the etch-figures a means of measuring and describing the position of the chief-knots and the course of the chief-paths; in short, the form-system of the crystals of this mineral species, even in those cases where Nature has furnished crystals with only a few faces. For the first time, we are now in a position consistently to explain and to compare those crystals that are poor in forms; to comprehend accurately the analogies between the form systems of different crystal species; and to draw conclusions with regard to the active particle-forces as respects their direction, intensity, and common action, even in the cases of imperfect development. This holds good not only in the case of crystals in the mineral-kingdom, but also with respect to the host of those formed in the chemist's laboratory, which are all poor in form. This whole domain must in this sense be revised, and it promises most valuable information. The chemist, however, recognizing the importance of this task, must cultivate or produce sufficiently large and good crystals, and must himself take part in the measurement, for the number of active crystallographers, though doubtless increasing gradually, is not large enough to take over the task.

A still deeper insight into the nature of the process of dissolution is given by those bodies which we have called *dissolution-forms* (*Lösungskörper*). These are bodies (residual forms) produced when a sphere ground from a crystal, for instance, of calcite, is etched and further subjected to solvent action. Associated with a young American mineralogist, Dr. F. E. Wright, I have made and published investigations on this subject. The results were as valuable as they were surprising. It is difficult to give an idea of these wonderful forms without presenting them to your view, but you can easily prepare similar ones for yourselves, therefore a few hints may perhaps suffice to induce some of you to undertake the study of them.

I shall speak of calcite, but further investigation has shown that what has been discovered about this mineral is of general application. If I treat a sphere of calcite—I shall take for this purpose pure Iceland spar, but less pure material will suffice (for example, the large American calcites from Joplin, Missouri)—

if I treat a sphere of calcite, I repeat, for a few seconds with strong acid a great many etchings are formed upon it. They are arranged in rows following the great circles which cut each other at the chief-knots (chief-faces). The rows are the zone-lines, the knots the positions of the chief-faces of calcite. Thus we find engraved upon the sphere the form system of calcite. Further, if we set the treated sphere on the two-circle goniometer and measure the light-paths (*Züge der Reflexe*) we obtain anew, in the picture of these paths, now however with greater clearness, the form-system of calcite.

If we continue the process of dissolution, something quite unexpected occurs. Exactly where the rows of etch-holes were first excavated, there arise prominent, sharp edges, which intersect forming pointed corners just on the spots where the chief-knots are located: We have thus once more the form-system of calcite before us, but in a new guise.

We will call the so formed bodies derived from the sphere through dissolution by preference, *dissolution-bodies*. They show the forms of the crystal in its course of destruction; when in a state of *disappearance*, or of *dissolution* just as what we usually call crystal forms are the forms of the crystal in its course of construction, or of growth. To the study of the domain of crystal forms, which illustrates the process of growth, is added therefore as a new field of research that of the solution bodies, which illustrate the process of dissolution. In the study of crystals and of dissolution-bodies, we find chiselled on their surface by Nature's hand the history of their growth and decay; just as the historian, from monuments and documents, reads of the rise and fall of the Roman Empire. We must, however, learn to read Nature's handwriting. But Nature is patient and kind to us. As soon as we cause a crystal to grow, or a crystal sphere to be dissolved, she writes down for us her story, truly and fully, as often as we wish, and then leaves the documents in our hands to read them over and over and study them out in detail.

Solution bodies and crystal forms present this remarkable reciprocal relation—where the dissolution-body presents an edge, the grown crystal shows a zone, and vice versa. But we will not here further discuss these interesting points. The discussion would lead us too far into crystallographic details.

As we have said before, these dissolution-bodies and etch-figures enable us to form a basis for a mechanical theory of the process of dissolution, and this is a problem which arouses the interest of the scientific world far beyond the bounds of crystallography proper. To indicate the way in which this may be done, we will now attempt to get an idea of the manner in which etch-figures develop. To begin with, experience shows that these figures are brought out exclusively on the *chief-faces* and in the *chief-zones*. Therefrom it comes, that they can serve as marks for the recognition of faces as the most important and primary ones, and that the positions of the chief-faces and chief-zones on the etched sphere are recognizable from the spots on which etch-holes occur. We will, therefore, first consider the process by which these depressions are formed on a chief-face, and in order to grasp this fact in a more concrete manner by means of an example, let us take a chief-face of calcite dissolved with hydrochloric acid. From the process here going on we can picture to ourselves the following. We assume that the chief-faces are at right angles to the chief attraction-forces of the particle. These particles situated side by side form the face. Their attractive forces acting inwards hold them together. It is the cause of their *cohesion* and *strength*. The free ends of these forces all arranged parallel to one another outwardly attract exterior particles at right angles to the face. Thus they attract the molecules or particles suspended in a liquid in contact with the crystal.

We assume now, and this is our hypothesis, that the CaCO_3 particles which form the face in contact, attract perpendicularly to the face by means of their mutual tendency to chemical action, the dissolved HCl particles; whereupon the chemical action is carried out which transforms $\text{HCl} + \text{CaCO}_3$ into $\text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$.

As fast as the HCl particles are neutralized, CaCl_2 particles being formed, fresh HCl particles take their place. Thus there arise two currents, one a *reaction-current* at right angles to the face, and at the same time a return current also at right angles to the same face and carrying off the products of the reaction. Since both currents directed alike but in opposite directions affect the whole face, both must separate into individual streamlets which give place to each other. At the border of the inflowing and out-

flowing streamlets eroding whirlpools arise which engrave the etch-depressions, until the face becomes covered as though with pock marks. That is our notion of the generation of the etch-figures.

In the case of amorphous substances, the little depressions have the form of skull-caps: they resemble microscopic finger-prints in plastic clay. In the case of crystals they have a style of their own—that is, they are bordered by regularly curved facets, due to the orienting cooperation of the particle-forces perpendicular to the face with those which are not at right-angles to it.

We see now how the same forces which unite the particles, the forces of cohesion, are those which attract the aggressive solvent in the process of dissolution, and at the same time resist it. This presentation furnishes us with the key to the process. Similarly in war the front draws on the enemy and repulses him. Thus likewise gravitation, which holds the hills together, attracts at the same time the destroying rain which digs holes in the surface, cuts channels, and causes all those phenomena which in geology are summed up under the head of erosion.

As a matter of fact the most perfect analogy exists between dissolution and erosion, so that we can study the mechanism of dissolution in that of erosion and vice versa. Similarly the whirls of air, bore holes into the stones of the desert and into the meteorites during their furious rush through the atmosphere and engrave on their surface erosion-figures of the same shapes, which are characteristic of the dissolution process. We see here several wide fields of investigation interconnected in such a way that the one throws rays of light upon the other.

If we have on the crystal not a chief-face, but a *subordinate one*, subjected to the attack of the solvent: that is, if the chief attractive forces of the particles are not at right angles to the face, then the reaction current meets the face in an inclined direction. In this case the aggressive streams and the return streams which form the eroding whirls, do not act perpendicularly to the face. The phenomena are similar to those seen when rain beats against an inclined plane, or when the wind blows at an angle against a sand plain. Dune-like elevations are produced with a steep front and a sloping back, all similarly arranged with regard to the attacking current. The process of dissolution presents such dune-

like forms on faces that are not chief-faces. They are elevations that are called "etch hills." They, like the etch-holes, have a style of their own, that is, they are covered with regularly curved facets due to the orienting action of the particle-forces. The form and arrangement of the etch-hills give us information about the reaction-current and at the same time of the ways and means of attack and defence. This is again the mechanism of the process of dissolution. This mechanism will be satisfactorily explained only when it can be calculated. But a calculation is possible only after a foundation for such calculations has been obtained by a correct conception of the precepts of nature.

We are now in a position to understand also the forms produced by dissolution from crystal spheres, the so-called *dissolution* bodies. In the case of the sphere the position on the surface and the direction from the centre are of the same significance. A point on the sphere designates the direction of the particle-force and at the same time the position of the face at right angles to this direction. If this be a chief-point corresponding to a chief-face (that is, this direction is that of a chief-force of the particle) then the attack by means of the reaction current falls centrally upon this point and the etch-holes are formed there, as in the case of the face, but only in a limited area around it. (the chief knot-point). This area may be considered as plane. The greater the radius of the sphere is, the greater is this area. The same formation of excavations is shown at all the chief-knots, and in this way the direction of the chief particle-forces is marked upon the sphere. Moreover, depressions appear on the great circles lying between the chief-knots. They indicate the planes (zone-planes) in which two chief-forces of the particle enter into common action. This common action works in the case of face-formation according to the law of complication, and gives the derived faces their position in accordance with the laws of harmony. Therefore in this stage of the dissolution process the chief zones are marked by series of little holes resembling furrows formed by contiguous indentations and extending from chief-knot to chief-knot. There appears in them, not very sharp, however, the form-system of the mineral species, engraved in the sphere.

If the dissolution process be continued we find that there arises (as already mentioned) at each chief-point a sharply projecting

corner instead of the excavation. This astonishing phenomenon can be explained in the following way. The reaction-current, working perpendicularly bores the holes. (See Fig. 2.) In the

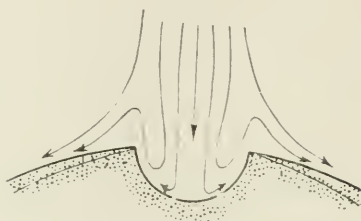


FIG. 2.

case of the sphere, however, (in contradistinction to the face) the reaction current strikes the curved face no longer vertically but slantingly at some distance from the knot, and slides sideways, carrying with it the edges of the excavations and forming in its course etch-hills, like rain water flowing down the sides of a crater. If the process continues, the edges of the excavations entirely disappear. (See Fig. 3.) The boring process ceases, since the reaction current no longer acts vertically, and in place of the depression there remains a sharp pointed elevation. This

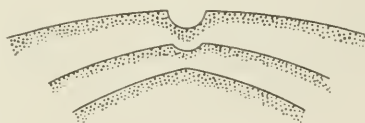


FIG. 3.

sharp point offers most resistance to the attack, and so maintains itself; since it is the direction of the greatest resistance of the particles, the direction of the chief attraction with which the particles cohere and with which they resist the action of the force tending to separate them.

In like manner the spires of towers and mountain peaks offer the greatest resistance to the attack of the rain. Furthermore, an umbrella is held with its point towards the rain which runs down its sides. Also the roofs of houses are built on this plan.

As in the knot-points of the sphere corners are formed on the spots, where holes were before; so also is a ridge formed instead of the series of excavations on the path of the zone-lines.

Now the current flows down on both sides of the ridge as does the rain on both sides of the mountain crest, and marks its course by etch hills forming striae in the direction of the slope and perpendicular to the strike of the crest. Thus we obtain the dissolution-body as the representation of equilibrium between attack and defence. In this dissolution-body, the form-system of the crystal species is indicated by corners at the chief-knots, by edges in the chief zones, by holes and hills, with characters which we must study and which we shall learn to read like those on the ruins of Memphis and Babylon. In these characters there is engraved a complete account of the course of the process of dissolution, in the various stages; all of which we can obtain by interrupting and continuing the process at pleasure.

The dissolution bodies so produced are of extreme beauty and variety. Each solvent writes its own handwriting, varying with the degree of concentration and the temperature employed. In the case of continued dissolution the original corners and edges, shortly after being formed, begin to migrate. Their ways are governed by laws which in themselves are interesting subjects of study, and they give us at the same time an account of the solution's progress. Finally a state of equilibrium is reached in which corners and edges cease migrating. A form is obtained which we call an *end-body*. This body subjected to continued solvent action becomes smaller and smaller without altering its shape until it completely disappears.

I could entertain you for hours with narratives concerning this realm of the beautiful, with accounts of this new world of vanishing forms, with descriptions of ways and means of entering into this borderland which promises us insight into the nature and method of action of the crystal-building particles, and into the processes of growth and decay at the boundary line between the solid and fluid. But I must limit myself to these hints, since the time has flown which was apportioned to this address.

I should like to invite you to see all this for yourselves at close quarters and to accompany me into this wonderful domain. You would derive much pleasure from it. But you yourselves are

investigators in domains of your own. Let us, then, while each pursues his own course, extend the land of the borderland for combined effort in the furtherance of the knowledge of Nature and of the human mind.

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A CONTRIBUTION TO THE CHEMISTRY OF THE
TELLURATES

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A CONTRIBUTION TO THE CHEMISTRY OF THE TELLURATES.

INTRODUCTION.

The first systematic study of tellurium and its compounds was made by Berzelius in the early part of the last century. He showed that tellurium forms two oxygen acids, H_2TeO_3 and H_2TeO_4 . Berzelius prepared telluric acid in the crystalline form and showed that it has the composition $\text{H}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$. He prepared a large number of the salts of both tellurous and telluric acids and found that nearly all of the metals yield insoluble compounds with these acids. Consequently the tellurates were largely obtained in the form of precipitates. Berzelius made quite a detailed study of some of these compounds. In the case of others, however, the tellurate was prepared and but little more is recorded concerning it. The work of Berzelius is of great importance in that it has not only furnished us with a large number of facts concerning these compounds but also paved the way for a fuller investigation of their properties by later chemists.

Oppenheim, Becker, Staudenmaier, Retgers, Mylius, and Gutbier have each made important contributions to our knowledge of telluric acid and its salts.

All of the alkali metals, sodium, potassium, rubidium, and caesium yield soluble crystalline tellurates and these have received the attention of investigators to a greater extent than have the tellurates of the heavy metals. Indeed many of the tellurates that were obtained as precipitates by Berzelius appear not to have been studied at all by later investigators. An examination of the literature on the tellurates shows that detailed knowledge of most of them is wanting. Many of the properties that have been observed appear to be those of mixtures. This is doubtless

due to the fact that telluric acid possesses weak acid properties and has a great tendency to form basic salts, particularly with the heavy metals, and, in general, to form complex salts. It is frequently found that the line of demarcation between two of the tellurates as they separate from solution is so narrow that one salt is contaminated by another and sometimes by a third or a fourth. The tellurates of the alkali metals are the only ones that have hitherto been described as crystalline.

The following work was undertaken with a view of preparing a number of the tellurates and studying their properties. The work has been confined for the most part to the salts of potassium, silver, and mercury. Careful attention has been devoted to their preparation in the crystalline form. The ease with which the tellurates of silver and mercury are decomposed by water has made this problem particularly difficult. For the most part the salts appear at first as amorphous precipitates of varying composition and quickly alter in the mother liquor, their subsequent composition depending on the conditions in the solution.

TELLURIC ACID.

Berzelius¹ prepared telluric acid by oxidizing tellurium dioxide in alkaline solution with chlorine. From this solution he precipitated barium tellurate by means of barium chloride and subsequently treated the barium salt formed, with sulphuric acid. Sulphuric acid liberates free telluric acid from barium tellurate, insoluble barium sulphate being formed at the same time. Berzelius also oxidized tellurium dioxide by fusing it with potassium nitrate. From the potassium tellurate thus formed, he obtained barium tellurate from which, in turn, he liberated the free acid by means of sulphuric acid.

Oppenheim² obtained the acid by fusing tellurium dioxide with potassium hydrate and potassium chlorate. He used the method of Berzelius for preparing the free acid from the alkali tellurate.

Becker³ dissolved tellurium in nitric acid and oxidized the solution by means of lead peroxide. The lead tellurate obtained was decomposed by sulphuric acid.

Gutbier⁴ and Wagenknecht have shown that telluric acid can be prepared by oxidizing tellurium dioxide by means of hydrogen peroxide in a solution which is strongly alkaline with sodium or potassium hydroxide. The alkali tellurate which is obtained in this manner is treated with nitric acid and the telluric acid obtained in the free condition.

The telluric acid used in this work was obtained by purifying and oxidizing electrolytic tellurium prepared by the Baltimore Copper Co. This tellurium contains silver, copper, and selenium as its principal impurities. The acid was prepared by the method described by Staudenmaier.⁵ By this method free telluric acid is obtained by oxidation of tellurous acid by means of chromic acid. In many respects this method is superior to those in which sulphuric acid is used to set the telluric acid free. The yield is greater, the operation is more direct, and the sulphuric and selenic

¹Pogg. Ann., Vol. 32, p. 23.

²Jour. f. pr. Chem., Vol. 71, p. 266.

³Ann. Chem., Vol. 180, p. 256.

⁴Zeit. f. anorg. Chem., Vol. 40, p. 260.

⁵Zeit. f. anorg. Chem., Vol. 10, p. 189.

acids are eliminated in one of the first steps of the process which consists in purifying tellurium dioxide. These acids are apt to contaminate telluric acid prepared by the other methods, unless special precautions are taken.

The method as carried out in this work is as follows:

Tellurium is dissolved in aqua regia and the resulting solution freed from nitric acid by evaporating with excess of hydrochloric acid. After the hydrochloric acid solution has been diluted and filtered the tellurium is precipitated by means of sodium acid sulphite and repeatedly washed with hot water. The moist tellurium is oxidized with nitric acid and the resulting basic nitrate purified by recrystallization.

The purified basic nitrate is covered with several times its bulk of dilute nitric acid. A little more chromic acid is added to the solution than is required by the equation $3\text{TeO}_2 + 2\text{CrO}_3 + 3\text{H}_2\text{O} = 3\text{H}_2\text{TeO}_4 + \text{Cr}_2\text{O}_3$. When the mixture is boiled for some time the tellurium dioxide is completely oxidized to telluric acid according to the above equation. The solution is then concentrated over the water bath until a crystalline crust begins to form and allowed to cool slowly. The telluric acid separates as a compact crystalline layer which is easily removed from the solution and rinsed to free it from the mother liquor. If the nitric acid solution to which the chromic acid has been added is quite concentrated, telluric acid will separate from the hot solution in the form of fine crystals. The solution is cooled, decanted, and again concentrated over the water bath until crystals form. This operation is repeated as long as telluric acid separates from the mother liquor.

The telluric acid, which is green from the presence of chromium nitrate, is dissolved in hot water and recrystallized. If a white residue remains when the acid is dissolved, it is an indication that the amount of chromic acid was insufficient to oxidize all of the tellurium dioxide. A residue may remain even when the hot nitric acid solution is clear. This is due to the fact that tellurium dioxide is much more soluble in hot nitric acid than in cold, and so may separate with the telluric acid when the solution is cooled. In order to remove the chromium nitrate from the telluric acid and obtain a pure white product the acid must be recrystallized

from ten to twenty-five times, depending upon the amount of the chromium salt present.

It has been found possible to prepare fifteen hundred grams of the recrystallized acid in six weeks. The yield is about 80%. Telluric acid remains in the mother liquor along with the chromium nitrate, from which it cannot be readily separated as the solution becomes syrupy upon evaporation.

Telluric acid is readily soluble in either hot or cold water. It is much more soluble in hot water than in cold. Its solubility is decreased by the addition of nitric acid. This fact may be made use of in the separation of telluric acid from chromium nitrate. When concentrated nitric acid is added to a concentrated solution of these compounds telluric acid is precipitated; the chromium nitrate being soluble in nitric acid, remains in solution. If a solution of telluric acid is concentrated rapidly it does not crystallize but appears as a syrupy or gummy mass.

Telluric acid is dimorphous⁶ crystallizing in the hexagonal-rhombohedral and isometric systems. It usually crystallizes from its solutions in the rhombohedral system but regular octahedra are sometimes formed. The crystals are colorless and transparent. They have the composition represented by the formula $\text{H}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$.

Staudenmaier⁷ describes a second hydrate of telluric acid having the composition $\text{H}_2\text{TeO}_4 \cdot 6\text{H}_2\text{O}$ which he obtained by cooling an aqueous solution of telluric acid to zero.

Telluric acid is a weak acid showing but a feeble reaction to litmus. Gutbier⁸ found that telluric acid has about the same molecular conductivity as hydrocyanic acid or hydrogen sulphide. He determined the molecular weight of telluric acid by the freezing point method. From the results which he obtained he concludes that telluric acid should be represented by the formula $\text{Te}(\text{OH})_6$ and not $\text{H}_2\text{TeO}_4 + 2\text{H}_2\text{O}$.

When heated above 110° telluric acid loses water. According to Gutbier⁹ constant weight is obtained at 145° . He shows that the loss in weight at that temperature is not as great as that re-

⁶Gutbier—Studien über das Tellur, p. 18.

⁷l. c.

⁸l. c. /

⁹Studien über das Tellur., p. 16.

quired by the change of $\text{H}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ to H_2TeO_4 . Experiments carried out during the progress of this work have given similar results to those obtained by Gutbier.

Mylius¹⁰ states that $\text{H}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ is changed to $(\text{H}_2\text{TeO}_4)_n$ at about 140° . He calls the polymerized acid allotelluric acid and shows that its solutions have a much greater conductivity than the acid that has not been dehydrated. The conductivity of solutions of allotelluric acid, according to Mylius, diminishes upon standing. This may indicate that the acid gradually assumes the composition H_6TeO_6 when in solution.

While telluric acid may be considered a weak acid, a hot aqueous solution of it will attack many metals such as silver, mercury, lead, bismuth, copper, zinc, arsenic, antimony, tin, aluminum, cadmium, and nickel. A number of these metals are attacked by a cold solution of the acid.

SALTS OF TELLURIC ACID.

The types of salts that telluric acid forms may be represented as follows: $(2\text{M}_2\text{O} \cdot 3\text{TeO}_3)$, $(\text{M}'_2\text{O} \cdot 2\text{TeO}_3)$, $(\text{M}'_2\text{O} \cdot \text{TeO}_3)$, $(3\text{M}'_2\text{O} \cdot 2\text{TeO}_3)$, and $(3\text{M}'_2\text{O} \cdot \text{TeO}_3)$. Crystalline salts of all of these types are now known. With the possible exception of mercuric orthotellurate¹¹ (Hg_3TeO_6) no anhydrous crystalline salt has been described. It is claimed by Nandl and von Lang¹² that K_2TeO_4 exists as a crystalline salt in the anhydrous condition but its existence has been disputed¹³ by Retgers, Rammelsberg, Staudenmaier, and Gutbier.

Berzelius considered telluric acid a dibasic acid and accordingly called salts of the type $\text{M}'_2\text{TeO}_4$ normal tellurates and salts of the other types basic or acid tellurates according as they contain more or less metallic oxide than the normal salt. This nomenclature has been universally adopted in describing the tellurates and is adhered to in the following description. However,

¹⁰ Ber., Vol. 34, II, p. 2208.

¹¹ New salt.

¹² Wiener Akad. Ber., Vol. 43, p. 117.

¹³ Gutbier, Studien über das Tellur., p. 36.

salts of the type $M'_6\text{TeO}_6$ are termed ortho-tellurates from their evident relation to orthotelluric acid H_6TeO_6 .

We have both amorphous and crystalline salts of the type $M'_6\text{TeO}_6$ such as Ag_6TeO_6 ,¹⁴ $\text{Hg}''_3\text{TeO}_6$,¹⁵ Cu_3TeO_6 ,¹⁶ and Zn_3TeO_6 .¹⁰ These salts appear to be derived from the hexabasic acid H_6TeO_6 which is identical in composition with ordinary telluric acid.

The crystalline salts of the type $M_2\text{O} \cdot \text{TeO}_3$ contain two or more molecules of water, for example, $(\text{Na}_2\text{O} \cdot \text{TeO}_3 \cdot 2\text{H}_2\text{O})$,¹⁷ $(\text{K}_2\text{O} \cdot \text{TeO}_3 \cdot 2\text{H}_2\text{O})$,¹⁸ $(\text{Cs}_2\text{O} \cdot \text{TeO}_3 \cdot 3\text{H}_2\text{O})$,¹⁹ $(\text{Rb}_2\text{O} \cdot \text{TeO}_3 \cdot 3\text{H}_2\text{O})$,¹⁹ $(\text{Ag}_2\text{O} \cdot \text{TeO}_3 \cdot 2\text{H}_2\text{O})$,²⁰ $(\text{HgO} \cdot \text{TeO}_3 \cdot 2\text{H}_2\text{O})$.²⁰ These compounds may be considered acid salts of orthotelluric acid of the types— $(\text{Na}_2\text{H}_4\text{TeO}_6)$, $(\text{K}_2\text{H}_4\text{TeO}_6)$, $(\text{Cs}_2\text{H}_4\text{TeO}_6 \cdot \text{H}_2\text{O})$, $(\text{Ag}_2\text{H}_4\text{TeO}_6)$, $(\text{HgH}_4\text{TeO}_6)$.

Likewise the silver salt $(3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O})$,²⁰ which according to the nomenclature in vogue is a basic salt, may be considered an acid salt of the type $\text{Ag}_3\text{H}_3\text{TeO}_6$.

This view of the tellurates finds some confirmation in the experiments of Gutbier and Mylius on the molecular weight and electrical conductivity of telluric acid. It is also supported by the behavior of the hydrous tellurates when heated. Gutbier²¹ has shown that the alkali tellurates decompose with the liberation of oxygen before the water which they contain is entirely driven off. The silver salts mentioned do not give up all of their water until a temperature of 200° is reached. Oxygen is evolved from these salts at a temperature only a few degrees above this point.

Some of the crystalline tellurates contain more water than is required to make them derivatives of orthotelluric acid; such salts are $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$ ²² and $\text{HHgTeO}_4 \cdot 3\text{H}_2\text{O}$.²³ These com-

¹⁴Amorphous, Berzelius.

¹⁵Crystalline, new salt.

¹⁶Amorphous, new salts.

¹⁷Berzelius.

¹⁸Retgers, Zeit. f. phys. Chem., Vol. 10, p. 536.

¹⁹Norris and Kingman, Am. Chem. Jr., Vol. 26, p. 320.

²⁰New salts.

²¹Studien über das Tellur., p. 34.

²²Berzelius.

²³New salt.

pounds may be considered acid salts containing water of crystallization, thus,— $\text{K}_2\text{H}_4\text{TeO}_6 \cdot 3\text{H}_2\text{O}$ and $\text{HgH}_5\text{TeO}_6 \cdot \text{H}_2\text{O}$.

Such crystalline salts as $\text{CsHTeO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ and $\text{RbHTeO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ ²⁴ would have to be considered salts of a higher acid, as $\text{H}_6\text{Te}_2\text{O}_9$.

Corresponding to the type $\text{M}'_2\text{TeO}_4$ a large number of anhydrous tellurates have been prepared but they are all amorphous. These salts may also be considered metatellurates. Their relation to orthotelluric acid is similar to that which the metaborates bear to orthoboric acid. It is problematical how much water these salts would contain were it possible to prepare them in the crystalline condition.

In addition to the types of tellurates enumerated above a number of tellurates corresponding to $\text{M}_2\text{Te}_2\text{O}_7$ have been prepared. They have been called the pyrotellurates. Berzelius also described the salts $\text{Na}_2\text{O} \cdot 4\text{TeO}_3 \cdot 5\text{H}_2\text{O}$ and $\text{K}_2\text{O} \cdot 4\text{TeO}_3 \cdot 4\text{H}_2\text{O}$.

METHODS OF ANALYSIS.

Many of the metals may be precipitated from solutions of the tellurate under conditions that will allow all of the tellurium to remain in the filtrate. Thus silver was determined in some cases by precipitation as chloride from a solution of the tellurate in dilute nitric acid.

In the analysis of the tellurates of those metals where chlorides are not volatile below a red heat the tellurium has been volatilized as $\text{TeO}_2 \cdot 2\text{HCl}$ and the non-volatile chloride weighed. This method of determining the metal is preferred to the method of precipitation because it is less time-consuming; there are fewer operations required for the analysis and less opportunity for experimental error. In cases where it is applicable, that is, where the chloride of the metal is not readily volatile, it gives at once a clean separation of the metal from telluric acid. Moreover the tellurium is obtained in a suitable solution for precipitation with sulphur dioxide.

²⁴Norris and Kingman, l. c.

Professor Lenher²⁵ has shown that when dry hydrochloric acid gas is passed over a tellurite heated to a temperature somewhat below redness the tellurium is completely volatilized as $\text{TeO}_2 \cdot 2\text{HCl}$. If the chloride of the metal is not volatile it remains in the boat. He has employed this method in the analysis of a number of the tellurites. The method has been found to work equally well for the analysis of salts of telluric acid. Following is a description of the method as it has been carried out.

A sample of the tellurate to be analyzed is placed in a porcelain boat which has been weighed. The boat is loosely covered with a thin glass plate and introduced into a hard glass tube. Hydrochloric acid gas is generated by allowing concentrated hydrochloric acid to drop slowly into a flask containing concentrated sulphuric acid. In this manner a steady stream of the gas is provided. The gas after having been dried by sulphuric acid is passed through the tube, which is heated to a dull red heat. The hydrochloric acid decomposes the tellurate with the formation of the chloride of the metal, chlorine, and $\text{TeO}_2 \cdot 2\text{HCl}$ according to the following equation: $\text{M}_2\text{TeO}_4 + 6\text{HCl} = 2\text{MCl} + 2\text{Cl} + \text{TeO}_2 \cdot 2\text{HCl} + 2\text{H}_2\text{O}$. The tellurium compound sublimes upon the cold part of the tube in the form of crystalline flakes leaving only the chloride of the metal in the boat. The boat is removed from the tube, cooled in a desiccator and weighed. The escaping hydrochloric acid gas is collected in a receiver containing cold water. The tellurium may be washed from the tube into the receiver with hydrochloric acid and precipitated with sulphurous acid. Tellurium was repeatedly determined by this method.

The method which Norris and Kingman²⁶ used in the analysis of the tellurates was largely employed for the estimation of tellurium. This method depends upon the fact that hot aqueous hydrochloric acid completely reduces telluric acid to tellurium tetrachloride with the liberation of free chlorine, according to the following equation: $\text{H}_2\text{TeO}_4 + 6\text{HCl} = \text{Cl}_2 + \text{TeCl}_4 + 4\text{H}_2\text{O}$. This reaction goes on only slowly, if at all, in the cold. The analysis is carried out as follows:

²⁵ Unpublished notes.

²⁶ l. c.

The sample to be analyzed is placed in a small round-bottomed flask together with a small piece of magnesite. About fifty cubic centimeters of concentrated hydrochloric acid is added. The solution is heated until about one-third of it has distilled over, the distillate being collected in a solution of potassium iodide kept cool by a freezing mixture. The liberated iodine is titrated with a solution of sodium thiosulphate.

To test the accuracy of this method a weighed amount of recrystallized telluric acid was decomposed by hydrochloric acid. The chlorine liberated by the reaction was absorbed by a solution of potassium iodide and the liberated iodine titrated with a solution of sodium thiosulphate. The solution of sodium thiosulphate was standardized against pure iodine. 0.4465 grams of telluric acid liberated chlorine equivalent to 0.2482 grams of tellurium. $\text{H}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ requires 55.56% Te; found 55.59%.²⁷

If it is desired, the metal may be determined in the solution after the tellurate has been reduced and the chlorine distilled. This was done in some cases where the amount of material at hand was small.

Tellurium can be determined in telluric acid or its salts much more quickly by this method than by any method requiring precipitation of elementary tellurium. The entire determination requires less than one hour. Moreover the method has proven more reliable as carried out in this work than precipitation of elementary tellurium by sulphur dioxide.

In separating mercury from telluric acid use has been made of the fact that tellurium sulphide is soluble in a solution of ammonium sulphide. The tellurate of mercury is dissolved in dilute hydrochloric acid. Mercurous compounds are oxidized by chlorine or bromine water. If the acid solution is saturated with hydrogen sulphide in the cold only a trace of telluric acid is reduced.²⁸ The solution of telluric acid is then decanted from the

²⁷ All calculations have been made on the basis of Te = 127.6.

²⁸ Brauner, Jr. Chem. Soc., Vol. 67, p. 545.

precipitated HgS . The precipitate is washed by decantation with hydrogen sulphide water to free it from telluric acid, and then digested with ammonium sulphide to remove the trace of tellurium precipitated with the mercuric sulphide.

Instead of decanting the solution of telluric acid from the precipitated mercuric sulphide it may be made strongly ammoniacal and saturated with hydrogen sulphide. Telluric acid is reduced at once by hydrogen sulphide in alkaline solution. The precipitate that is formed dissolves immediately in ammonium sulphide forming a yellow solution. All of the tellurium will now be found in the solution. The mercuric sulphide is washed with a solution of ammonium sulphide and hydrogen sulphide water, dried at 110° and weighed.

Water was determined in most cases by heating the tellurate in a current of dry air and collecting the water in sulphuric acid.

THE TELLURATES OF SILVER.

NORMAL SILVER TELLURATE.

Berzelius²⁹ describes normal silver tellurate (Ag_2TeO_4) as a dark yellow precipitate. He states that he obtained this compound in the form of bulky flakes by adding a concentrated solution of silver nitrate to a solution of normal potassium tellurate. If the precipitate is treated with boiling water it is converted into a brown basic silver tellurate.

Gutbier³⁰ states that it is hardly possible to prepare normal silver tellurate in pure condition by the method described by Berzelius. According to Gutbier the precipitate obtained from concentrated solutions of silver nitrate and potassium tellurate is always contaminated with a larger or smaller amount of basic silver tellurate.

It has not been found possible to prepare normal silver tellurate (Ag_2TeO_4) in pure condition by precipitation as described by Berzelius. When solutions of silver nitrate and normal potassium tellurate are brought together, the precipitate contains basic silver tellurate. The formation of a basic salt may be obviated by using an acid tellurate of potassium, for example, KHTeO_4 , in place of the normal tellurate. But under these conditions the precipitate may contain an excess of telluric acid. Moreover when the precipitate is washed it is decomposed forming a basic tellurate of silver.

It has been found possible to prepare well crystallized normal silver tellurate. Crystals of this salt are not rapidly attacked by cold water and may be obtained free from basic salts.

Silver tellurate has been obtained by the following methods: the action of telluric acid upon silver oxide; the double decomposition of a soluble silver salt with a soluble tellurate or telluric acid; the action of telluric acid upon metallic silver.

²⁹ Pogg. Ann. d. Phys. u. Chem., Vol. 32, p. 577.

³⁰ Zeit. f. Anorg. Chem., Vol. 31, p. 340.

Action of Telluric Acid on Oxide of Silver.

When silver oxide is treated with a slight excess of a solution of telluric acid, normal silver tellurate is formed according to the equation: $\text{Ag}_2\text{O} + \text{H}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O} = \text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O} + \text{H}_2\text{O}$.

The silver tellurate obtained by this method has quite different physical properties from the yellow precipitate described by Berzelius and Gutbier. It is a heavy granular powder nearly white in color. It has the composition $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$. It is much more stable in the presence of water than the yellow precipitate hitherto described. When the powder is heated to 100° it loses a part of its water and assumes a brown color; but it does not give up all of its water until a much higher temperature is reached. It is soluble in ammonium hydrate, sodium thiosulphate, and the acids. The white powder reacts with silver oxide suspended in hot water to form a brown basic tellurate of silver.

If a solution of $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ in acetic or nitric acid is evaporated to dryness *in vacuo* telluric acid and silver acetate or nitrate are formed. When the salt is strongly compressed between steel rolls it detonates and assumes a brown color. The same property is possessed by the tellurates of mercury. This work will be continued later.

For analysis the salt was dried over sulphuric acid and dissolved in dilute nitric acid. The silver was precipitated from the solution by dilute hydrochloric acid. The filtrate was evaporated with an excess of hydrochloric acid to free it from nitric acid. The tellurium was precipitated in the hydrochloric acid solution by sulphurous acid.

Analysis gave the following results:

0.9597 grams gave 0.6172 grams AgCl and 0.2755 grams Te .
0.9051 grams gave 0.0724 grams H_2O .

	Ag	Te	H ₂ O
Calculated for $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ —	48.68%	28.77%	8.11%
Found	48.40%	28.06%	7.99%

Crystalline $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$.

It has been found possible to obtain crystals of normal silver tellurate by slowly evaporating a solution made by bringing together dilute solutions of telluric acid and silver acetate containing free acetic acid. The dilute acetic acid holds the tellurate of silver in solution and allows it to crystallize as the solution is evaporated. The acetic acid solution must be quite dilute, as a strong solution of the acid prevents the formation of silver tellurate.

When solutions of silver acetate and telluric acid of moderate concentration are brought together a lemon yellow precipitate is formed. The precipitate closely approximates Ag_2TeO_4 in composition. When a solution of silver acetate containing 2.0 grams of silver acetate and a few drops of free acetic acid per liter, is mixed with an equal volume of a solution of telluric acid containing 1.4 grams of the acid per liter, no precipitate is formed. When such a solution is allowed to evaporate in the dark at room temperature yellow crystals of $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ are formed. The free telluric acid in the solution prevents the decomposition of the normal salt by the water. Only small amounts of the salt have been prepared in this manner. Larger quantities of the salt are more conveniently prepared in the following manner:

Upon adding an excess of a solution of silver nitrate to a concentrated solution of potassium tellurate containing a little free acetic acid a yellow or brown precipitate is formed. Analysis showed that this precipitate approximates normal silver tellurate in composition. Its exact composition depends largely on the concentration of the solution. It was observed that when such a solution is allowed to remain in contact with the precipitate for a few hours a heavy yellow salt separates at the bottom of the beaker. The salt is composed of distinct crystals of a straw yellow color. As the crystals have a much higher specific gravity than the amorphous precipitate, they can easily be separated from it by elutriation. If the precipitate is allowed to remain in the mother liquor for several days, red crystals of a basic silver tel-

lurate will usually be found among the yellow crystals of the normal salt.

Analysis of the yellow crystals gave the following results:

0.7638 grams gave 0.0605 grams H_2O .

0.4847 grams gave 0.3117 grams AgCl .

0.4980 grams when heated with hydrochloric acid gave sufficient chlorine gas to liberate 0.2828 grams of iodine from potassium iodide.

	H_2O	Ag	Te
Calculated for $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$	8.11%	48.68%	28.77%
Found	7.92%	48.41%	28.57%

In this analysis the silver was precipitated with hydrochloric acid from a dilute nitric acid solution of the salt.

Silver acetate or sulphate may be used instead of silver nitrate for the preparation of the salt by double decomposition with potassium tellurate and subsequent change of the amorphous precipitate to the crystalline salt. Likewise the free acetic acid may be replaced by nitric acid, or the acid may be omitted altogether. The salt crystallizes much better, however, when the solution contains free acid.

$\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ crystallizes in the orthorhombic system. The crystals resemble those of sulphur both in the forms that occur and in the axial ratios. They are insoluble in hot or cold water but soluble in ammonia, potassium cyanide, sodium thiosulphate, and nitric, acetic and sulphuric acids. Concentrated nitric, acetic, or sulphuric acids completely decompose silver tellurate, giving free telluric acid and the corresponding silver salt.

When crystals of the normal salt are allowed to remain for some time in contact with a cold solution of a silver salt, red crystals of the basic tellurate $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$ are formed. The change is much more rapid in a ten per cent solution of silver nitrate at a temperature of 50° than in the cold. It takes place very slowly even in cold water.

Crystals of $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ darken slowly when exposed to the light. When the powdered crystals are compressed between steel rolls they detonate. When heated above 100° the crystals lose water and take on a brilliant purplish black lustre. They maintain this lustre until a temperature of about 200° is reached.

As the temperature is raised still higher oxygen is evolved, the mass assumes a gray brown color and fuses. If the mass is allowed to cool as soon as it fuses, it becomes black and crystalline, but if it is heated to bright redness it is completely changed to silver tellurite, which is white when cold.

The crystalline normal salt may be prepared entirely free from basic silver tellurate by allowing the precipitate obtained by mixing solutions of silver nitrate and acid potassium tellurate to remain in the mother liquor until it assumes the crystalline form.



Orthorhombic. Axes— $a:b:c=0.722:1:2.107$.³¹

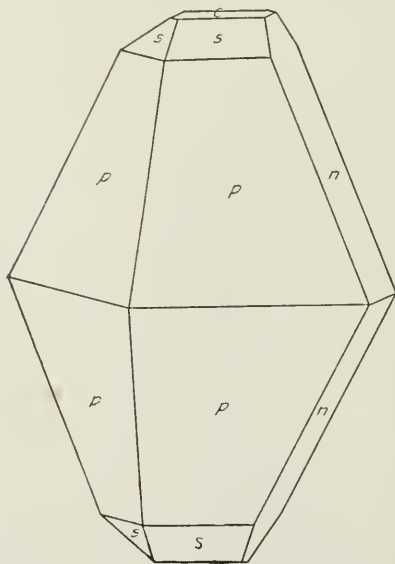
pp''' , $III:\bar{I}I=III^\circ 26'$.

pp' , $III:\bar{I}II=77^\circ 25'$.

cp , $00I:III=105^\circ 40'$.

cn , $00I:0II=115^\circ 29'$.

cs , $00I:II3=103^\circ 02'$.



³¹The author is indebted to Professor Hobbs for his kindly advice in that part of this work which deals with the crystallography of the tellurates.

The crystals that were used for measurement were obtained by double decomposition of solutions of silver nitrate and potassium tellurate containing a little free acetic or nitric acid. The amorphous precipitate that formed on mixing the solutions slowly dissolved in the free acid, while at the same time crystals of $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ were formed upon the walls of the containing vessel.

In order to determine whether silver sulphate and silver tellurate are isomorphous, crystals of $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ were introduced into a saturated solution of silver sulphate and the solution allowed to evaporate. Silver sulphate crystallized out of the solution entirely independent of the silver tellurate. Silver sulphate (Ag_2SO_4) and silver tellurate ($\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$) are therefore not isomorphous. It may be stated that the tellurate of silver was decomposed by the solution to some extent, a few red crystals of a basic tellurate being formed.

The sulphate and selenate of silver are isomorphous, their axial ratios being as follows:

Silver sulphate $a:b:c = 0.5712 : 1 : 1.238$

Silver selenate $a:b:c = 0.5945 : 1 : 1.256$

However, these salts cannot properly be compared with the tellurate of silver since they are anhydrous, while silver tellurate contains two molecules of water.

In addition to the tellurate of silver described by Berzelius Oppenheim³² describes a crystalline precipitate, which he obtained in small quantity by adding a saturated solution of telluric acid to a concentrated solution of silver nitrate. He states that it differs from any tellurate of silver obtained by Berzelius in that it is crystalline and colorless. When exposed to the air it assumed a yellow color, according to Oppenheim. He states that he did not make a quantitative analysis of the substance but concluded that it was a double compound of silver tellurate and nitrate, since he found that it contained nitric and telluric acids together with silver.

³² Jr. pr. Chem., Vol. 71, p. 266.

Gutbier³³ attempted to prepare the crystalline compound described by Oppenheim. When a concentrated solution of telluric acid is added to a concentrated solution of silver nitrate a red brown or yellow precipitate is formed. This precipitate is the only product that Gutbier obtained from such solutions.

When a solution of silver nitrate is added to a dilute solution of telluric acid no precipitate is formed. But if the solutions are sufficiently concentrated and an excess of telluric acid added, a yellow flocculent precipitate is formed in small quantity. If the solution and precipitate are allowed to remain together in a dark place at room temperature for a few hours the amorphous precipitate changes to straw yellow crystals of $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$. This is the crystalline compound that Oppenheim obtained. Under the conditions of the experiment the crystals might easily be contaminated by silver nitrate.

ACID TELLURATES OF SILVER.

Berzelius states that concentrated solutions of KHTeO_4 and $\text{K}_2\text{Te}_4\text{O}_{13}$ react with concentrated solutions of silver nitrate to form the corresponding tellurate of silver. If the solution containing the precipitate is evaporated to dryness, a white earthy residue remains. Berzelius states that the acid tellurates are transformed to a brown basic tellurate of silver in dilute solutions.

Attempts were made to prepare the acid tellurate of silver described by Berzelius. It was not found possible to obtain precipitates having either the composition AgHTeO_4 or $\text{Ag}_2\text{Te}_4\text{O}_{13}$. The precipitates obtained in the manner described by Berzelius contain more telluric acid than is required by normal silver tellurate (Ag_2TeO_4), but upon remaining in the mother liquor for some hours they are largely transformed to crystalline $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$. It would hardly be expected that a solution of KHTeO_4 would yield AgHTeO_4 with silver nitrate, when it is known that telluric acid and silver nitrate give the crystalline normal tellurate.

When concentrated solutions of KHTeO_4 and silver nitrate are brought together a bright yellow precipitate is formed. The

³³l. c.

lemon yellow color of the amorphous precipitate is permanent, there being no tendency to form a brown basic tellurate in the medium present. Analysis of the precipitate obtained in this manner showed that it contained 46.6% silver and 32.9% tellurium. The ratio between the silver and telluric acid in the precipitate lies between those required by the formulae Ag_2TeO_4 and AgHTeO_4 . Some of the precipitate was allowed to remain in the mother liquor for forty-eight hours. At the end of that time a large part of it had been converted into crystalline normal silver tellurate.

When a concentrated solution of silver nitrate is added to a solution of acid potassium tellurate made by dissolving potassium hydrate and telluric acid together in the proportions required by the formula $\text{K}_2\text{Te}_4\text{O}_{13}$ a bright yellow precipitate is formed. When left in contact with the mother liquor for some time the precipitate is largely changed to crystalline $\text{Ag}_2\text{Te}_4\text{O} \cdot 2\text{H}_2\text{O}$.

Analysis of the crystalline salt obtained in this manner gave the following results:

0.4006 grams gave 0.0329 grams H_2O and 0.2571 grams AgCl .

0.5384 grams with HCl liberated chlorine equivalent to 0.1555 grams Te .

Found H_2O , 8.21% ; Te , 28.88% ; Ag , 48.31%.

The silver tellurate prepared in this manner is not well crystallized. This is due to the fact that the precipitate is only slightly soluble in the mother liquor. The crystals darken only very slowly in direct sunlight.

When solutions of HKTTeO_4 and silver nitrate are brought together in equimolecular proportions and the whole evaporated to dryness a white residue remains. Analysis of the residue obtained in this manner and washed with a little hot water shows that it contains telluric acid in excess of that required by normal silver tellurate. The residue also contains potassium. It is not possible to determine how much of the telluric acid is combined with the potassium, or how much of it is in the form of the free acid. Consequently no conclusion can be reached as to the exact composition of the silver tellurate in the residue. It is not fea-

ible to wash it thoroughly because of the decomposition that silver tellurate undergoes in the presence of water.

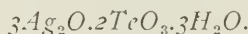
When crystals of normal or basic silver tellurate are boiled with a concentrated solution of telluric acid, a bright yellow amorphous precipitate is formed which is similar to the one obtained from solutions of acid potassium tellurate and silver nitrate.

BASIC SILVER TELLURATES.

Berzelius³⁴ describes two basic tellurates of silver, $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3$ and $3\text{Ag}_2\text{O} \cdot \text{TeO}_3$, both of which were obtained as brown precipitates. He states that boiling water decomposes the normal tellurate of silver into $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3$ and telluric acid.

When a dilute solution of silver nitrate is added to a dilute solution of potassium tellurate, the dark yellow precipitate which is first formed quickly assumes a dark brown color. Berzelius found this dark brown precipitate to be $3\text{Ag}_2\text{O} \cdot \text{TeO}_3$. He also prepared this compound by adding an ammoniacal solution of silver nitrate to a solution of normal silver tellurate in ammonia and evaporating the solution. The basic tellurate separates from the solutions as a brown black precipitate.

Gutbier³⁵ states that the precipitate formed by the action of silver nitrate on potassium tellurate may be completely changed to $3\text{Ag}_2\text{O} \cdot \text{TeO}_3$ by long continued washing with cold water. He states that when the precipitate is washed with hot water the final product is $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3$. According to Gutbier this salt may be prepared by bringing together hot dilute solutions of silver nitrate and potassium tellurate.



In addition to the brown precipitates of $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3$ and $3\text{Ag}_2\text{O} \cdot \text{TeO}_3$ already described, a crystalline tellurate of silver having the composition $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$ was prepared during the progress of this work. When the precipitate obtained by

³⁴l. c.

³⁵l. c.

the double decomposition of moderately dilute solutions of silver nitrate and potassium tellurate assumes the crystalline condition, both yellow crystals of $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ and red crystals of $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$ are formed. The relative amounts of these salts obtained depends largely upon the temperature of the solutions and their concentration. When the solutions are cold and concentrated but little of the basic salt is formed. On the other hand, if the solutions are very dilute and warm, it is possible to obtain the crystalline basic tellurate free from the normal salt.

Analysis of the red crystals gave the following results:

0.2812 grams gave 0.0653 grams Te

0.3763 grams gave 0.2917 grams AgCl

1.6094 grams gave 0.0797 grams H_2O

	Te	Ag	H_2O
Calculated for $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$	23.18%	58.83%	4.90%
Found	23.22%	58.35%	4.95%

$3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$ crystallizes in ruby red, transparent crystals belonging to the monoclinic system. The crystals remain unchanged in cold water. They are gradually decomposed by boiling water with the formation of a brown residue, probably $3\text{Ag}_2\text{O} \cdot \text{TeO}_3$. When boiled with an excess of a concentrated solution of telluric acid a bright yellow amorphous precipitate results which probably contains silver bi-tellurate (AgHTeO_4). The crystals are soluble in the same reagents that dissolve normal silver tellurate. In the sunlight the crystals become opaque and assume a copper color. When heated above 110° they lose water and become black, but all of the water is not given up until a temperature of about 200° is reached.

Just as it is possible to obtain crystals of hydrous normal silver tellurate by evaporation of solutions of silver tellurate under proper conditions, so it is possible by varying the conditions to obtain crystals of $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$ directly from clear solutions. If a dilute solution of potassium tellurate is added to a large excess of silver nitrate containing a little free nitric acid, the solution filtered and allowed to evaporate at room temperature, red crystals of the basic salt are formed. The formation of crystals when the solution is evaporated is made possible by the

fact that the dilute nitric acid is saturated with silver tellurate dissolved from the amorphous precipitate. If the solution contains much nitric acid the silver tellurate is entirely decomposed with the formation of silver nitrate and telluric acid so that no crystals of the tellurate of silver appear when the solution is evaporated. Consequently a large volume of solution is necessary in order to obtain a small amount of the crystalline salt. Crystals of $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$ have been repeatedly obtained in this manner, but only in small quantities.

Larger quantities of the salt have been prepared by double decomposition of solutions of silver nitrate and potassium tellurate and subsequent change of the amorphous precipitate thus obtained into the crystalline salt. If the solution contains no free acid the crystals form only in contact with the amorphous precipitate, since silver tellurate is insoluble in water. If, however, the solution contains a little free nitric or acetic acid, red crystals of $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$ frequently form on the walls of the containing vessel. By working with dilute solutions at temperatures from 15° to 50° and using a large excess of silver nitrate, it has been found possible to obtain the red crystalline salt entirely free from yellow crystals of the normal salt. In most cases, however, more or less of the normal salt was formed. Both of the salts appear in distinct crystals. Their colors are so different that it is easy to ascertain when one salt contaminates the other and to remove it mechanically if it is present in small amount.



Monoclinic. Axes— $a:b:c=0.5290:1:0.2706$. $\beta=77^\circ 12'$.

$$mm''', \quad 110:1\bar{1}0=125^\circ 24'.$$

$$ll, \quad 111:1\bar{1}1=154^\circ 28'.$$

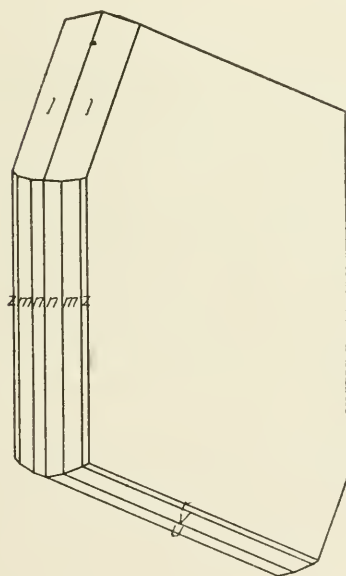
$$nn''', \quad 210:2\bar{1}0=150^\circ 00'.$$

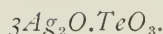
$$rb, \quad 13\bar{1}:010=127^\circ 43'.$$

$$vb, \quad 12\bar{1}:010=118^\circ 00'.$$

$$ub, \quad 11\bar{1}:010=104^\circ 33'.$$

$$zz''', \quad 230:2\bar{3}0=104^\circ 30'.$$





Silver orthotellurate ($3\text{Ag}_2\text{O}.\text{TeO}_3$) has not been obtained in the crystalline form. It is known only in the form of the brown amorphous precipitate described by Berzelius. The salt, somewhat contaminated by $3\text{Ag}_2\text{O}.\text{TeO}_3$, was obtained by adding a hot dilute solution of potassium tellurate to a solution of silver nitrate containing free nitric acid. Analysis of the precipitate, which had been thoroughly washed with hot water and dried over sulphuric acid, gave 72.9% silver. $3\text{Ag}_2\text{O}.\text{TeO}_3$ requires 74.3% silver.

The filtrate was allowed to evaporate at room temperature. Crystals of $3\text{Ag}_2\text{O}.2\text{TeO}_3.3\text{H}_2\text{O}$ formed in the solution.

1. The precipitate obtained by double decomposition of a silver salt with telluric acid or a soluble tellurate, may vary in composition from a mixture containing more telluric acid than Ag_2TeO_4 to $3\text{Ag}_2\text{O}.\text{TeO}_3$, depending upon the conditions in the medium.

2. It has not been found possible to obtain the acid tellurates of silver, AgHTeO_4 and $\text{Ag}_2\text{O}.4\text{TeO}_3$ described by Berzelius.

3. Silver forms two crystalline tellurates— $\text{Ag}_2\text{TeO}_4.2\text{H}_2\text{O}$, which appears as yellow crystals belonging to the orthorhombic system, and $3\text{Ag}_2\text{O}.2\text{TeO}_3.3\text{H}_2\text{O}$, whose crystals are red and belong to the monoclinic system.

4. The crystalline compound that Oppenheim described as a double salt of silver tellurate and silver nitrate, is $\text{Ag}_2\text{TeO}_4.2\text{H}_2\text{O}$.

5. No sulphates or selenates of silver have been prepared that are analogous to the crystalline tellurates of silver.

THE TELLURATES OF POTASSIUM.

NORMAL POTASSIUM TELLURATE.

Berzelius³⁶ states that normal potassium tellurate can be prepared by treating potassium carbonate with telluric acid. These compounds were dissolved together in equimolecular quantities and the solution evaporated to dryness. The residue was dissolved in water and the solution evaporated *in vacuo* over sulphuric acid until a crystalline crust formed. According to Berzelius this crust consisted of normal potassium tellurate. If the solution is evaporated at a moderate temperature a gummy mass is deposited.

Gutbier³⁷ states that he was not able to obtain normal potassium tellurate by this method.

Experiments were undertaken to ascertain whether normal potassium tellurate could be obtained by this method. It was found that solutions made by dissolving equivalent quantities of potassium carbonate and telluric acid in water always yield a gummy mass when they are evaporated *in vacuo*.

Potassium tellurate crystallizes from its solutions if they are allowed to evaporate very slowly. This separation of the crystalline salt is aided by the addition of a few crystals of the salt. When solutions, made according to the directions of Berzelius, are evaporated in this manner no crystals are formed. The gummy mass even separates around the crystals of $K_2TeO_4 \cdot 5H_2O$, introduced into the solution. This pasty mass evolves carbon dioxide when treated with hydrochloric acid. The same result is obtained if the solution is cooled to zero instead of evaporated.

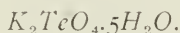
That all of the carbon dioxide appearing in the gummy mass had not been absorbed from the air is shown by the following experiment: 1.42 grams of anhydrous potassium carbonate and 2.37 grams of telluric acid were dissolved in a little water. The solution was at once evaporated to dryness over a free flame.

³⁶Pogg. Ann., Vol. 32, p. 579.

³⁷Zeit. f. anorg. Chem., Vol. 31, p. 340.

The residue copiously evolved carbon dioxide when treated with hydrochloric acid. It is evident that telluric acid cannot replace all of the carbonic acid in an equimolecular quantity of potassium carbonate. This fact is in harmony with the fact, observed by Berzelius, that carbon dioxide reacts on normal potassium tellurate to form acid potassium tellurate, KHTeO_4 , and potassium carbonate.

No carbon dioxide is evolved when saturated solutions of acid potassium tellurate (KHTeO_4) and potassium carbonate are brought together at 95° in the proportion of two molecules of the acid tellurate to one of the carbonate. KHTeO_4 is more soluble in a solution of potassium carbonate than in water.



Berzelius³⁸ prepared crystalline $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$ from concentrated solutions of potassium hydrate and telluric acid in the following manner: A solution of potassium hydrate was added to a solution of telluric acid until a permanent precipitate formed, indicating the presence of an excess of the alkali. The gummy precipitate was dissolved by warming the solution. Crystals of $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$ separated from the solution upon cooling it to zero. The salt is decomposed by carbon dioxide with the formation of KHTeO_4 and potassium carbonate.

Gutbier³⁹ obtained $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$ in the form of long slender needles by employing the method of preparation used by Berzelius. Gutbier states that it is very difficult to obtain the salt free from adhering alkali since it cannot be recrystallized without adding free alkali to the solution of the salt.

Retgers⁴⁰ describes a second crystalline tellurate of potassium ($\text{K}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$) which he prepared by dissolving telluric acid in a concentrated boiling solution of potassium hydroxide and allowing the solution to cool slowly. He states that crystals of $\text{K}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$ are isomorphous with those of $\text{K}_2\text{OsO}_4 \cdot 2\text{H}_2\text{O}$.

³⁸l. c.

³⁹l. c.

⁴⁰Zeit. f. phys. Chem., Vol. 10, p. 536.

Gutbier⁴¹ also prepared $K_2TeO_4 \cdot 2H_2O$ by dissolving telluric acid in hot concentrated potassium hydroxide and cooling the solution. He found the salt to be isomorphous with $K_2OsO_4 \cdot 2H_2O$.

Nandl and von Lang⁴² describe crystalline anhydrous potassium tellurate (K_2TeO_4) which they found to be isomorphous with potassium sulphate. Gutbier, Rammelsberg, Staudenmaier, and Retgers have been unable to prepare the anhydrous crystalline tellurate.⁴³

$K_2TeO_4 \cdot 5H_2O$ may be obtained in the form of crystals by slow evaporation of solutions of the salt at room temperatures. Whenever solutions of potassium tellurate are allowed to evaporate *in vacuo* over sulphuric acid they solidify to a gummy mass which does not become crystalline until it is dry. In order to bring about slower evaporation of the solution the loosely covered dish containing the solution may be placed in a desiccator over sulphuric acid. The desiccator should be filled with air freed from carbon dioxide to prevent the formation of potassium carbonate and acid potassium tellurate. Potassium tellurate has been repeatedly crystallized from its solutions in this manner. The solution may be concentrated rapidly until its specific gravity is about 1.2 and then crystallized by slow evaporation. The fact that potassium tellurate is very soluble renders it somewhat difficult to obtain a nicely crystallized product. Frequently the crystals form radiating clusters but in other cases the crystals are distinct. Solutions of potassium tellurate that have become supersaturated can frequently be made to crystallize by adding a few crystals of $K_2TeO_4 \cdot 5H_2O$ and preventing further evaporation by closely covering the solution. Even under these conditions crystallization proceeds slowly.

Crystals of $K_2TeO_4 \cdot 5H_2O$ may be obtained by slow evaporation of the solution resulting from the double decomposition of equivalent quantities of normal silver tellurate and potassium bromide solution. This may be readily accomplished in the following manner. The potassium bromide and silver tellurate are

⁴¹l. c.

⁴²Wiener Akad. Ber., Vol. 43, p. 117.

⁴³Gutbier, Studien über das Tellur., p. 36.

thoroughly ground together, treated with a little warm water and again triturated. After standing for some time in an atmosphere free from carbon dioxide the solution is filtered and crystallized in the manner described above.

Analysis of crystals obtained in this manner gave the following results:

0.9742 grams gave 0.2420 grams H_2O .

0.9742 grams gave 0.4010 grams KCl .

0.2839 grams with hydrochloric acid liberated chlorine equivalent to 0.1001 grams Te .

	Calculated for $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$	Found
H_2O	25.01	24.84
K	21.76	21.60
Te	35.45	35.26

Crystals of $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$ are soft and crumble under a slight pressure. Solutions of the salt are alkaline to litmus and attack glass.

Solutions of potassium tellurate containing two molecules of free potassium hydroxide to one of the tellurate yield crystals of $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$ when evaporated slowly. The yield is small on account of the free alkali in the solution. Solutions of this kind were evaporated in order to ascertain whether potassium tellurate would crystallize with two or five molecules of water under these conditions.

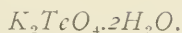
Crystals that had been washed with water and dried with filter paper gave the following results upon analysis:

1.1936 grams gave 0.3000 grams H_2O .

1.1936 grams gave 0.4916 grams KCl .

0.6443 grams with hydrochloric acid liberated chlorine equivalent to 0.2306 grams Te .

	Calculated for $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$	Found
H_2O	25.01	25.15
K	21.75	21.63
Te	35.45	35.79



This salt was obtained in the form of distinct crystals by dissolving telluric acid in a hot concentrated solution of potassium hydrate and allowing the solution to cool. The yield was very small.

Analysis of the salt after having been washed with water at zero and dried for a day over calcium chloride gave the following result:

1.4806 grams gave 0.1767 grams of water.

Calculated for $K_2TeO_4 \cdot 2H_2O$

11.47

Found

11.93

When the solution of potassium hydrate, from which the crystals of $K_2TeO_4 \cdot 2H_2O$ had been removed, was diluted a copious amount of $K_2TeO_4 \cdot 5H_2O$ separated as small crystals. This fact indicates that the formation of the dihydrate in the concentrated solution is due to the dehydrating effect of the strong alkali. It is also evident that $K_2TeO_4 \cdot 5H_2O$ is less soluble in a dilute solution of potassium hydrate than $K_2TeO_4 \cdot 2H_2O$ is in a concentrated solution.

ACID TELLURATES OF POTASSIUM.

Berzelius states that potassium bitellurate ($KHTeO_4$) may be obtained from equivalent quantities of telluric acid and potassium carbonate, but that it is produced with greater certainty by dissolving potassium carbonate and telluric acid in a small amount of hot water in such proportions that there shall be two molecules of telluric acid present to one of potassium carbonate. When such a solution is cooled the bitellurate of potassium separates upon the walls of the containing vessel in granular tufts. The formula $K_2O \cdot 2TeO_3 \cdot 4H_2O$ is assigned to the crystalline salt.

Berzelius states that potassium quadrotellurate ($K_2O \cdot 4TeO_3$) can be obtained by the same method as the bitellurate. In the case of the quadrotellurate, however, telluric acid and potassium carbonate were dissolved in the proportion of four molecules of the former to one of the latter. The formula $K_2O \cdot 4TeO_3 \cdot 4H_2O$

is assigned to the crystalline salt. Berzelius states that these salts may also be obtained by treating a solution of normal potassium tellurate with the requisite amount of an acid (nitric or sulphuric) to withdraw potassium.

Berzelius also describes a yellow insoluble quadrotellurate of potassium obtained by heating either $K_2O.2TeO_3$ or $K_2O.4TeO_3$. He states that this compound may also be obtained by heating telluric acid with potassium nitrate at a temperature below a red heat. The compound is insoluble in cold nitric, hydrochloric, and sulphuric acids, and potassium hydrate.



A tellurate of potassium containing more telluric acid than $KHTeO_4$ cannot be obtained by the action of carbon dioxide on normal potassium tellurate. When carbon dioxide is passed into a concentrated solution of potassium tellurate a white precipitate of potassium bitellurate ($KHTeO_4$) is immediately formed. The precipitate may settle as a gummy mass, but it becomes granular when cooled to zero. The composition of this precipitate is not changed by prolonged contact with carbon dioxide. $KHTeO_4$, obtained in this manner, was repeatedly covered with distilled water, cooled to zero, and treated with carbon dioxide.

Analysis of the residue, after having been dried with filter paper, gave the following results:

0.5428 grams with hydrochloric acid liberated chlorine equivalent to 0.2415 grams Te.

0.9906 grams gave 0.2511 grams KCl.

1.5444 grams gave 0.3492 grams H_2O .

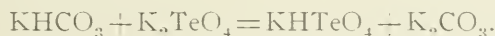
Found 44.49% Te; 13.30% K; and 22.62% H_2O .

After deducting the water, some of which was evidently held mechanically, the values obtained for potassium and tellurium correspond closely with those required by the formula $K_2O.2TeO_3$. In another experiment 18% of water was obtained from a sample dried with filter paper, while the same sample gave 13.2% of water after having been dried over phosphorus pentoxide for several days. The calculated value for water in $KHTeO_4.2H_2O$ is

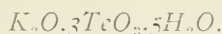
16.8%, and for $\text{KHTeO}_4 \cdot 1\frac{1}{2}\text{H}_2\text{O}$ (or $\text{K}_2\text{O} \cdot 2\text{TeO}_3 \cdot 4\text{H}_2\text{O}$) 13.9%. The latter formula is the one assigned to the bitellurate by Berzelius.

Potassium bitellurate may be obtained in the form of a transparent crystalline crust by slow evaporation of its solutions. It is only sparingly soluble in water at 0° ; but is readily soluble in boiling water. It is alkaline to litmus.

When a solution of potassium bicarbonate is added to a concentrated solution of normal potassium tellurate a white precipitate is formed. The precipitate appears flocculent when it is first formed, but it settles as a gummy mass. The precipitate is so soluble in the menstruum present that a large amount of potassium tellurate is required to obtain a small amount of the solid material. The precipitate is probably potassium bitellurate. Its solubility in the menstruum may be due to potassium carbonate formed by the reaction—



This reaction is in harmony with the fact, mentioned above, that potassium bitellurate does not react with potassium carbonate to give carbon dioxide. The ready formation of potassium bitellurate may be due largely to the insolubility of the compound, but from the facts that have been mentioned it seems probable that telluric acid is a weaker acid than carbonic.



When solutions made by dissolving potassium carbonate and telluric acid together in water in the proportion of one molecule of the carbonate to four of the acid are evaporated, a white granular precipitate of $\text{K}_2\text{O} \cdot 3\text{TeO}_3 \cdot 5\text{H}_2\text{O}$ is deposited. Analysis of the salt, after having been dried for eleven days over phosphorus pentoxide, gave the following results:

1.6971 grams gave 0.2075 grams H_2O .

1.6971 grams gave 0.3495 grams KCl .

1.3340 grams gave (with HCl) chlorine equivalent to 0.7207 grams Te .

	Calculated for $K_2O \cdot 3TeO_3 \cdot 5H_2O$	Found
H_2O	12.65	12.22
K	11.01	11.06
Te	53.83	54.02

The salt reacts alkaline to litmus. Like the bitellurate it is much more soluble in hot water than in cold.

This acid salt may be obtained by dissolving potassium carbonate and telluric acid together in the ratio of one molecule of potassium carbonate to three of telluric acid.

MERCUROUS TELLURATES.

Berzelius⁴⁴ describes normal mercurous tellurate (Hg_2TeO_4) as a yellow-brown precipitate obtained by adding powdered mercurous nitrate to a solution of potassium tellurate. When a solution of mercurous nitrate is used instead of the powdered salt, the yellow-brown precipitate gradually changes to a pale yellow color. Berzelius states that this change in color is probably due to the formation of the bitellurate of mercury ($HgHTeO_4$) brought about by the free acid in the solution of the mercury salt.

Oppenheim⁴⁵ states that when a concentrated solution of mercurous nitrate is treated with telluric acid a white cheesy precipitate forms which becomes yellow in the air. He considers this precipitate a double salt of mercurous nitrate and tellurate analogous to the double compounds of silver and lead that he describes.

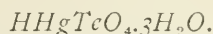
The precipitates obtained by double decomposition of solutions of mercurous nitrate and a soluble tellurate or telluric acid may vary in composition from $HHgTeO_4$ to $3HgO \cdot 2TeO_3$.

However, any precipitate of mercurous tellurate may be changed to crystals of $HHgTeO_4 \cdot 3H_2O$ by treatment with a cold concentrated solution of telluric acid. This acid tellurate is not only the only crystalline mercurous tellurate that has been prepared, but it is the only mercurous tellurate of definite composition that has been obtained during the progress of this work.

⁴⁴Pogg. Ann., Vol. 32, p. 577.

⁴⁵Jr. f. pr. Chem., Vol. 71, p. 266.

Mercurous tellurate is a striking example of a salt of a weak acid and a weak base. Slight variations of the conditions under which a salt is placed may bring about a change in its composition, causing it to become either more acid or more basic. This, together with the fact that the salt is readily decomposed giving free mercury and mercuric tellurate, renders the preparation of the tellurates of monovalent mercury somewhat difficult.



This crystalline salt may be obtained either by double decomposition of solutions of mercurous nitrate and telluric acid or by the action of telluric acid upon mercurous oxide.

When mercurous oxide is treated with a cold concentrated solution of telluric acid it is slowly attacked and colorless crystals of $\text{HHgTeO}_4 \cdot 3\text{H}_2\text{O}$ are formed. As the resulting crystals are mixed with the unattacked oxide, this is not a suitable method for the preparation of the salt in pure condition.

Large amounts of the salt may be conveniently prepared by treating a solution of mercurous nitrate with telluric acid and subsequent change of the precipitate to the crystalline salt. When a solution of telluric acid is added to a solution of mercurous nitrate a bright yellow precipitate is formed. If a large excess of telluric acid is added, the yellow precipitate becomes nearly white and slowly changes to colorless crystals of $\text{HHgTeO}_4 \cdot 3\text{H}_2\text{O}$. The presence of considerable free nitric acid in the solution aids greatly in the formation of crystals of the salt. Under these conditions crystals frequently form on the walls of the containing vessel.

Analysis of the colorless crystals gave the following results:

1.9265 grams gave 0.2717 grams H_2O .

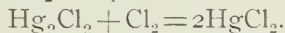
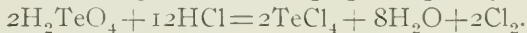
0.8459 grams gave 0.4358 grams HgS .

1.2416 grams with hydrochloric acid liberated chlorine equivalent to 0.3501 grams Te .

	Calculated for $\text{HHgTeO}_4 \cdot 3\text{H}_2\text{O}$	Found
Hg	44.78	44.40
Te	28.57	28.21
H_2O	14.11	14.11

For the estimation of the mercury, all of which was present in the mercurous condition, the salt was treated with dilute hydrochloric acid and the precipitated mercurous chloride oxidized with bromine water. The mercury was precipitated with hydrogen sulphide.

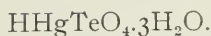
Tellurium was estimated by decomposing the salt with hydrochloric acid, absorbing the liberated chlorine in a solution of potassium iodide and titrating the free iodine with sodium thio-sulphate. The chlorine absorbed by the solution of potassium iodide represents only a portion of the chlorine liberated by the oxidation of the hydrochloric acid. When the tellurate is treated with hydrochloric acid in the cold, mercurous chloride is precipitated. Upon heating the solution the chlorine formed by the oxidation of the hydrochloric acid converts the mercurous chloride into mercuric chloride. The amount of chlorine thus reduced was calculated and added to the amount absorbed by the iodide solution in order to determine the amount of tellurium in the salt. The reactions involved may be represented as follows:



One-half of the chlorine liberated during the reaction is reduced by the mercurous chloride in the solution.

$\text{HgHTeO}_4 \cdot 3\text{H}_2\text{O}$ crystallizes in the triclinic system. It is insoluble in water but soluble in dilute acetic or nitric acid. Ammonium hydroxide reacts with the salt to form a black precipitate. Sunlight blackens the salt, but it is stable in the air if protected from the light. Crystals of the salt have been preserved in closed tubes for a year without losing their transparency or changing in any respect. With boiling water the crystals quickly decompose, telluric acid and a yellow amorphous tellurate being formed. An excess of cold concentrated mercurous nitrate solution brings about the same result. If the yellow basic precipitate is treated with an excess of telluric acid it may be changed to crystals of $\text{HHgTeO}_4 \cdot 3\text{H}_2\text{O}$. When strongly compressed between steel rolls the salt detonates and assumes a brown color. The amorphous mercurous tellurates possess the same property. It has been observed that when a glass rod is drawn over the wet

precipitate obtained by bringing together solutions of mercurous nitrate and potassium tellurate, it changes from a yellow to a brown color. The same change may be brought about by pressing the precipitate between layers of filter paper.



Triclinic. Axes— $a:b:c=1.044:1:1.055$

$$\alpha=100^\circ 30'; \beta=106^\circ 03'; \gamma=103^\circ 59'.$$

$$\text{ca, } 001:100=109^\circ 38'.$$

$$\text{ab, } 100:010=108^\circ 00'.$$

$$\text{cb, } 001:010=105^\circ 30'.$$

$$\text{cs, } 001:011=141^\circ 45'.$$

$$\text{cx, } 001:\bar{1}11=127^\circ 07'.$$

$$\text{sx, } 011:\bar{1}11=141^\circ 30'.$$

$$\text{c'r, } 00\bar{1}:\bar{1}1\bar{1}=131^\circ 32'.$$

$$\text{as, } 100:011=114^\circ 05'.$$

$$\text{bx, } 010:\bar{1}11=130^\circ 15'.$$

$$\text{c'h, } 00\bar{1}:01\bar{1}=126^\circ 08'.$$

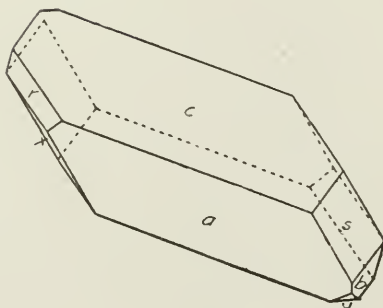
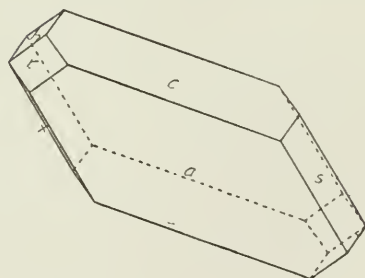
$$\text{hs, } 01\bar{1}:011=92^\circ 23'.$$

$$\text{ub, } 22\bar{3}:010=133^\circ 25'.$$

$$\text{uc', } 22\bar{3}:00\bar{1}=103^\circ 30'.$$

$$\text{rb, } \bar{1}1\bar{1}:010=106^\circ 00'.$$

$$\text{xa', } \bar{1}11:\bar{1}00=104^\circ 25'.$$



Other Mercurous Tellurates.

All attempts to prepare normal mercurous tellurate in the crystalline form have been unsuccessful. Indeed, it has not been found possible to obtain an amorphous tellurate of mercury having exactly the composition Hg_2TeO_4 . The salt is likely to be contaminated by either a basic or an acid tellurate of mercury, depending upon the conditions in the solution. The preparation of the salt is still further complicated by the fact that the precipitate obtained by double decomposition of mercurous nitrate and potassium tellurate contains nitric acid which it is difficult to remove by washing. Moreover, long continued treatment with water decomposes the precipitate.

When a large excess of a cold concentrated solution of potassium tellurate is added to a concentrated solution of mercurous nitrate the yellow precipitate, which is first formed, quickly changes to a brown. The precipitate is slimy and difficult to wash. It approximates Hg_2TeO_4 in composition.

Impure $3\text{Hg}_2\text{O} \cdot 2\text{TeO}_3$ may be obtained as a yellow amorphous precipitate by treating a hot dilute solution of potassium tellurate with an excess of mercurous nitrate solution and washing the precipitate with hot water. It is hardly possible to obtain the precipitate free from nitric acid.

A mercurous tellurate analogous or silver orthotellurate (Ag_6TeO_6) has not been prepared. When the bulky yellow precipitate, obtained by treating a hot dilute solution of potassium tellurate with an excess of mercurous nitrate solution is washed with hot water and boiled for some time in water it is decomposed giving free mercury. The precipitate may be boiled for several hours without changing in appearance, but at length it settles as a heavy brown granular powder containing free mercury. This change may be hastened by rubbing some of the precipitate against the side of the beaker with a glass rod.

When the brown powder is heated with hydrochloric acid elementary tellurium is precipitated.

MERCURIC TELLURATES.

Berzelius describes mercuric tellurate (HgTeO_4) as a white flocculent precipitate.

Divalent mercury forms two salts with telluric acid, mercuric orthotellurate (Hg_3TeO_6) and normal mercuric tellurate (HgTeO_4), both of which have been prepared in crystalline form. HgTeO_4 may be obtained as a white flocculent precipitate as described by Berzelius. Under favorable conditions it crystallizes with two molecules of water, giving $\text{HgTeO}_4 \cdot 2\text{H}_2\text{O}$. The intermediate compound $3\text{HgO} \cdot 2\text{TeO}_3$ has not been isolated, although there are indications that it may exist. All precipitates of mercuric tellurate, whether crystalline or amorphous, show a strong tendency in the presence of water to change to mercuric orthotellurate. This property of mercuric tellurate renders it difficult to prepare HgTeO_4 in pure condition.

Mercuric Orthotellurate— Hg_3TeO_6 .

When an excess of mercuric nitrate is added to a hot dilute solution of potassium tellurate, a heavy yellow granular precipitate of mercuric orthotellurate is formed. In order to obtain this salt in crystalline form, a somewhat different method of procedure must be employed.

If a cold concentrated solution of mercuric nitrate is added to a concentrated solution of potassium tellurate made acid with nitric acid, a white flocculent precipitate of HgTeO_4 is formed. At room temperatures a portion of the precipitate usually assumes a yellow color immediately, probably due to the formation of a basic salt. If the acid solution containing this white or yellow flocculent precipitate is allowed to stand undisturbed for several days the precipitate is largely converted into transparent amber colored crystals of Hg_3TeO_6 . Frequently the walls of the containing vessel are covered with crystals that have separated from the acid solution. In many cases the amber colored crystals form in contact with the white amorphous precipitate, but

in all cases the crystals are entirely distinct from the precipitate.

Hg_3TeO_6 crystallizes in the isometric system, the predominating form being the dodecahedron. Combinations of the cube and dodecahedron are frequent, while many crystals show a broad octahedral face on which the crystal has grown. Single crystals have been obtained which are over an eighth of an inch in diameter. The crystals contain a little nitric acid and about 0.6% of water. This is considerably less than one-half of a molecule of water to one of Hg_3TeO_6 .

The crystals are insoluble in water and unchanged by boiling with water. They are soluble in nitric acid but more readily soluble in hydrochloric acid. Hot potassium hydrate precipitates mercuric oxide. The powdered salt does not change in composition when kept in contact with a cold saturated solution of telluric acid for 48 hours.

When heated the salt assumes a red color, but it regains its original color upon cooling. The crystals are not altered by heating to 140° .

Analysis of the salt, after having been dried over phosphorus pentoxide for several days, gave the following results:

4.6696 grams gave 0.0279 grams H_2O .

1.7853 grams gave 1.4940 grams HgS .

1.0894 grams with hydrochloric acid liberated chlorine equivalent to 0.1727 grams Te .

Found 72.13% Hg 15.85% Te 0.59% H_2O

The value obtained for tellurium is about 0.5% too high. This discrepancy is due to the presence of a little nitric acid in the crystals.

The corresponding sulphate of mercury, Hg_3SO_6 , exists as turpeth mineral. This compound may be prepared as a heavy yellow powder or as yellow crystals by treating the normal sulphate with water. In color the sulphate is very similar to the tellurate, but it does not crystallize in the isometric system.

Amorphous Hg_2TeO_4 .

When concentrated solutions of mercuric nitrate and potassium tellurate or telluric acid are brought together at zero a white

flocculent precipitate of mercuric tellurate is formed. The precipitate is quickly decomposed by water at room temperature into telluric acid and basic mercuric tellurate. This decomposition goes on even when the precipitate is washed with water at zero; consequently it is impossible to obtain a pure white product in suitable condition for analysis. The precipitate remains white indefinitely in a saturated solution of telluric acid at room temperature.

Analysis of the light yellow powder obtained by washing the white precipitate with water at 0° showed that it approximates HgTeO_4 in composition.

Crystalline $\text{HgTeO}_4 \cdot 2\text{H}_2\text{O}$.

If the white precipitate of mercuric tellurate formed by mixing concentrated solutions of mercuric nitrate and potassium tellurate containing free nitric acid, is allowed to remain undisturbed in the mother liquor for several days at room temperature, nearly all of it is converted into crystalline Hg_3TeO_6 . In some cases colorless crystals of $\text{HgTeO}_4 \cdot 2\text{H}_2\text{O}$ were obtained mixed with the amber colored crystals of mercuric orthotellurate.

Analysis of the colorless crystals gave the following results:

0.2413 grams gave 0.0202 grams H_2O ;

0.2413 grams gave 0.0887 grams TeO_2 ;

	Calculated for $\text{HgTeO}_4 \cdot 2\text{H}_2\text{O}$	Found
Te	29.84	29.39
H_2O	8.41	8.37

$\text{HgTeO}_4 \cdot 2\text{H}_2\text{O}$ appears as transparent crystals belonging to the orthorhombic system. It is slowly decomposed by cold water. Boiling water quickly decomposes it into telluric acid and basic mercuric tellurate.

Copper Orthotellurate, Cu_3TeO_6 .

When a solution of copper nitrate is treated with a solution of potassium tellurate a green flocculent precipitate of copper tellurate is formed. Berzelius describes this compound as normal copper tellurate (CuTeO_4). If the precipitate is boiled for some

hours with water it is converted into copper orthotellurate, which settles as a heavy green powder. It is insoluble in water but soluble in ammonia, potassium cyanide, and acetic, hydrochloric, and nitric acids.

Analysis of the green powder after having been dried over phosphorus pentoxide for a week gave the following result:

0.6675 grams heated with hydrochloric acid liberated chlorine equivalent to 0.2069 grams tellurium.

Cu_3TeO_6 requires 30.79% tellurium; found 31.00%.

Numerous attempts were made to prepare copper tellurate in crystalline form, but none were successful. Copper hydrate was treated with an excess of telluric acid; the resulting tellurate of copper was allowed to remain in the solution for several weeks. Likewise the precipitate obtained by bringing together solutions of potassium tellurate and copper nitrate was allowed to remain in mother liquors of varying composition for weeks. In no case were any crystals of copper tellurate formed.

Zinc Orthotellurate, Zn_3TeO_6 .

The white flocculent precipitate obtained by bringing together solutions of zinc nitrate and potassium tellurate may be changed into a heavy granular precipitate of Zn_3TeO_6 by long continued treatment with hot water.

Analysis of the powder prepared in this manner and dried over phosphorus pentoxide for a week gave the following result. 0.6331 grams with hydrochloric acid liberated chlorine equivalent to 0.1940 grams tellurium. Calculated for Zn_3TeO_6 , 30.40% tellurium; found 30.64%.

Zn_3TeO_6 is insoluble in water but soluble in acetic, nitric, hydrochloric, and sulphuric acids.

Gutbier⁴⁶ prepared zinc tellurate in the form of a white insoluble precipitate by bringing together solutions of potassium tellurate and zinc chloride. He does not give the composition of the tellurate of zinc that he obtained in this manner.

⁴⁶ Zeit. f. anorg. Chem., Vol. 31, p. 349.

Attempts were made to prepare zinc tellurate in crystalline form by allowing the amorphous salt to remain in contact with mother liquors of various compositions. The results were all negative.

GOLD TELLURATE.

No tellurate of gold has been prepared. From the experiments that have been made in an attempt to prepare this salt it seems probable that water immediately decomposes the salt if it is formed in aqueous solutions.

When a solution of gold chloride is added to normal silver tellurate suspended in water, silver chloride and gold oxide are precipitated.

When solutions of normal potassium tellurate and gold chloride are brought together and the resulting solution allowed to evaporate over sulphuric acid, yellow crystals of potassium chloraurate are formed. No tellurate of gold separates from the solution.

The fact that gold chloride takes up potassium from potassium tellurate to form potassium chloraurate is a good illustration of the weak affinity that telluric acid exerts towards bases.

SEPARATION OF GOLD FROM TELLURIUM.

While working with gold and telluric acid it became necessary to separate gold from tellurium. It was found that nitrous acid would not reduce either telluric or tellurous acids. Nitrous acid completely reduces gold from its solutions.⁴⁷ Gold may be separated from tellurium in dilute acid solution by the addition of potassium nitrite. After filtering out the precipitated gold, tellurium may be determined in the filtrate by precipitation with sulphur dioxide.

⁴⁷Fischer, Pogg. Ann., Vol. 17, p. 480.

SUMMARY.

1. Telluric acid forms ortho-tellurates of the type $M'_6\text{TeO}_6$ with a number of the metals. Ag_6TeO_6 , Hg_3TeO_6 , Zn_3TeO_6 , and Cu_3TeO_6 have been prepared. The normal tellurates (e. g. Ag_2TeO_4) of these metals are changed to the ortho compounds by treatment with water.

2. The crystalline normal tellurates that have been prepared, viz.: $\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$, $\text{Rb}_2\text{TeO}_4 \cdot 3\text{H}_2\text{O}$, $\text{HgTeO}_4 \cdot 2\text{H}_2\text{O}$, $\text{Cs}_2\text{TeO}_4 \cdot 3\text{H}_2\text{O}$, $\text{Na}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$, and $\text{K}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$,⁴⁸ may be considered acid salts of orthotelluric acid of the types $M'_2\text{H}_4\text{TeO}_6$ and $M'_2\text{H}_4\text{TeO}_6 \cdot \text{H}_2\text{O}$.

3. Silver forms two crystalline tellurates— $\text{Ag}_2\text{O} \cdot \text{TeO}_3 \cdot 2\text{H}_2\text{O}$ and $3\text{Ag}_2\text{O} \cdot 2\text{TeO}_3 \cdot 3\text{H}_2\text{O}$. The former salt is yellow and crystallizes in the orthorhombic system; the latter is red and crystallizes in the monoclinic system. Both of these salts may be considered acid salts of orthotelluric acid. No selenate or sulphate of silver is known that is isomorphous with either of these salts.

4. $\text{HgHTeO}_4 \cdot 3\text{H}_2\text{O}$ crystallizes in the triclinic system. It is the only crystalline mercurous tellurate that has been prepared.

5. Two crystalline salts of divalent mercury have been prepared, viz.: Hg_3TeO_6 and $\text{HgTeO}_4 \cdot 2\text{H}_2\text{O}$. The former appears in the form of amber colored crystals belonging to the isometric system; the latter is white and crystallizes in the orthorhombic system.

6. The crystalline compound described by Oppenheim as a double salt of silver nitrate and tellurate is normal silver tellurate ($\text{Ag}_2\text{TeO}_4 \cdot 2\text{H}_2\text{O}$).

7. It has not been found possible to prepare the acid tellurates of silver described by Berzelius.

8. Potassium tellurate may be prepared in crystalline form by slow evaporation of its solution, provided care is exercised to prevent supersaturation of the solution.

⁴⁸Potassium forms a second tellurate— $\text{K}_2\text{TeO}_4 \cdot 5\text{H}_2\text{O}$.

9. Telluric acid does not completely replace the carbonic acid in an equivalent quantity of potassium carbonate. Crystalline normal potassium tellurate cannot be obtained from potassium carbonate and telluric acid as described by Berzelius.

10. Although telluric acid is a weak acid, hot concentrated solutions of it attack mercury, silver, lead, tin, arsenic, antimony, bismuth, nickel, zinc, aluminum, and cadmium.

11. There are no well authenticated cases of isomorphism between sulphates and tellurates or between selenates and tellurates.

This work was undertaken at the suggestion of Professor Lenher and carried out under his guidance. I wish to take this opportunity of expressing my thanks for the inspiration that I have received from him in the laboratory as well as in the classroom.

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ANATOMY IN AMERICA

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ANATOMY IN AMERICA.*

INTRODUCTION.

For over a quarter of a century anatomical studies have been carried on in the biological laboratories of this university, important contributions to the science have been made, and students trained here have achieved notable success as teachers, physicians and investigators.¹ During the past year facilities for teaching and research work have been extended so as to include the study of human structure, and a department of anatomy has been created. The new department maintains, in addition to human anatomy, the work in vertebrate comparative anatomy, neurology, histology and embryology, previously carried on in the zoological department. It has been my pleasant privilege to be called here to share in the development of this new department, and it has seemed to me that it might be of interest to some of you who are engaged in other fields of science to consider with me briefly the growth of the science of anatomy, what America has contributed to this growth, and what we hope to see Wisconsin contribute toward it.

Anatomy has for its objects the determination of the facts and laws of the form and structure of organisms.² It is a fundamental biological science because, so far as is known, structure determines all vital activities and maintenance of structure is necessary for their existence. Life we see maintained by a vast number of plants and animals each of which has arisen by an orderly

*An address delivered before the Science Club of the University of Wisconsin, November 15th, 1904, with some additions and numerous explanatory notes. I desire here to express my obligation to many friends and especially to my colleague, Professor W. S. Miller, for aid in the preparation of these notes.

specific structural differentiation from a part of one, or the union of parts of two, similar pre-existing organisms, and each of which in turn may give off parts of its substance to be again differentiated into new individuals similar to itself. The lowest organisms, both animal and vegetable, merely divide into two or more portions, each of which soon assumes the form of the parent. The more complex organisms, on the other hand, through structural differentiation, give rise to special parts, destined, if fate permit, to be developed into new individuals. Thus, plants give rise to seeds, animals to eggs, and the power of a seed or an egg to develop into an individual like the parent, we have reason to assume is conditioned by its structure. The ultimate nature of the structure of living substance can at present merely be surmised. On the one side, the anatomist, by means of the microscope and a highly developed technique, seeks to penetrate deeper and deeper into its mysteries; on the other side, the chemist, by increasingly refined methods, investigates its nature. But between the two there is a vast and, as yet, impenetrable area.³

Yet, when one considers the vague and erroneous ideas of organic structure entertained by the people of unenlightened nations, and the unenlightened people of nations where science is cultivated, one cannot but be astonished at the vast amount of anatomical knowledge that has been accumulated since the science had its birth among the Greeks.

ANCIENT ANATOMY.

Aristotle, who in the fourth century B. C. summed up the anatomical knowledge of his time and added to it, had some curiously erroneous ideas concerning structure and function. The brain, he thought, could not be the organ of the mind, as some physicians asserted, because he found that, when exposed, the brain of a living dog did not seem sensitive to touch. He did not distinguish nerves from tendons or arteries from veins, and he thought movements brought about not by the action of the muscles but by the tendons and veins. The flesh he took as an organ of sensation. The distinction between arteries and veins and the functions of the brain, the nerves and the muscles, were discovered in the follow-

ing century by Herophilus and Erasistratus, who studied at the great school at Alexandria, where, for the first time, the human body was dissected. It is interesting to note that in this century lived Euclid, the mathematician, Aristarchus, the great astronomer, and Archimedes, the founder of mechanics. From the Alexandrian school sprang many generations of Greek physicians whom the spirit of inquiry led to make advance in anatomical science. The last great man among these was Galen, who lived in the second century A. D., who compiled much of the work of his predecessors, bettered it in parts, and in part put error where truth was known. His studies were conducted on apes and other mammals, but not on the human body. He treated the subject strictly from the teleological point of view.⁴

Curiously enough, although Galen is most severe in his criticism of those of his predecessors who took authority of man in place of authority of nature, which alone is to be trusted, he himself became the great authority on anatomy, physiology, pathology and medicine, for over thirteen hundred years. Ptolemy Claudius, a contemporary, performed a similar service for astronomy.

During the middle ages what little was known of anatomy was derived from Galen. With the revival of learning in Italy, renewed interest was taken in the subject. The awakening needs of art were added to those of medicine, and at the beginning of the fourteenth century human dissection was once more occasionally permitted. Mondinus at this time wrote a book on anatomy which remained a favorite for two centuries and a half. This book was not, however, based much upon personal observations, but was rather a compilation from books derived through the Arabians from the works of Galen. Mondinus' explanations of structure are often curious. Thus: "The skull is formed of discontinuous pieces so that the fumosities may escape through the sutures and the forces of medicine may reach the brain."⁵

During the fourteenth and fifteenth centuries, however, some progress was made. By the end of the fifteenth a number of facts concerning human structure were known which were not found described by Galen, the original works of whom had mean-

while been discovered, circulated, and accepted as authorities in place of those of his Arabian commentators.⁶

RISE OF MODERN ANATOMY.

The times were ripe for a genius who could see all these new facts in their true relations and deliver anatomy from its bondage to the ancients. To Vesalius is chiefly due the honor of bringing this about. Three years before the death of Luther, and two after that of Paracelsus, in 1543, the year in which the epoch-making book "*De revolutionibus orbum cælestium*" was put into the hands of its dying but immortal author, Copernicus, Vesalius published his great book "*De corporis humani fabrica libri septem*." This book is still of worth as a treatise on human anatomy. Its greatest value, however, lies in the fact that in it, for the first time, was shown the value of accurate objective study and good illustration. However theories vary, facts thus recorded are of permanent value.⁷

During the half century following the appearance of Vesalius anatomy reached its zenith in the Italian universities. To them students flocked by thousands from many countries. Medicine and law were the most favored studies, and human anatomy, as the basis of medicine, received high honors. This the beautiful theatres still existing at Bologna and Padua attest. Since the sixteenth century anatomy has not held relatively so high a place in Italy as at that period, but at all times, down to the present, Italian investigators have steadily advanced the subject and, from time to time, there has appeared a great man to force it far ahead.

From Italy the study of human anatomy spread to other countries. In Spain it found sterile soil and failed to flourish permanently. In France it suffered somewhat from the quarrels which there divided physician and surgeon, and long made its chief advances under royal support and protection at the *Jardin des Plantes*. In England it did not receive much university support and had to be cultivated chiefly in private schools by physicians in active practice, usually at great personal cost. Yet the path to

fame and position lay here, and England may well be proud of the great men who forced their way along its difficult course.⁸

It was, however, with anatomy as with painting. The world's chief centre shifted from Italy to the Netherlands. And, as in Italy, Leonardo da Vinci the artist, and della Torre the anatomist, Titian and Vesalius were intimate friends, so here between the artists and the anatomists there existed a helpful friendship to which the great Rembrandt has borne witness in his well known "Lesson in Anatomy." The Dutch anatomists are as famous for the minute beauty of their preparations as the Dutch painters for the perfect finish of their canvasses.

From the Netherlands great influence was exerted upon anatomical study in all the surrounding countries, especially in England, Scotland, France, and Germany.⁹ Toward the end of the eighteenth century the chief advances in the science were being made in these countries. In Germany the liberal support given to the medical sciences in the universities during the nineteenth century led to an advance of anatomy equalled nowhere else.

The enormous development which anatomy has undergone since the time of Vesalius can be appreciated only by one well acquainted with the subject. Thousands of minds highly endowed have been eagerly devoted to its pursuit, and it has had its due share of men of genius to open up new and fruitful fields of work. A vast and complicated technique has been developed for furthering its growth. Numerous museums have been established for preserving specimens; beautiful and expensive laboratories have been built for its service. In Germany no university is too small or poor to deny it a specially designed and well constructed building.¹⁰

Several societies exist in different parts of the world for furthering its interests. Large libraries are devoted to the immense literature which deals with the special and general phases of the subject. Many periodicals¹¹ and new books each year are required to record its advance. Schwalbe's *Jahresberichte* for the year 1902 gives a list of nearly 4,000 articles dealing with vertebrate and general anatomy, by about 2,500 investigators.

DEVELOPMENT OF ANATOMY.

The anatomy of Vesalius was characterized by its clear, straightforward description of observed structure. His followers soon corrected the errors which he had made and carried their dissections into more and more remote parts of the body. In 1622 Aselli discovered the chyle vessels, in 1647 Pecquet the receptaculum of the chyle, and in 1651 Rubeck the lymphatics. Before many decades had passed most of the structures in the human body visible to the naked eye had been accurately described. Yet, even in this field of gross, descriptive human anatomy, new points of view are still from time to time brought forward and structures seen in new relations are truly seen for the first time.

Vesalius performed some experiments on animals to determine the functions of various organs. This led to further study of animal structure from the standpoint of comparative physiology. "From dissection of a living dog one can learn more in a day," said Colombo, "than in feeling pulses or studying Galen for many months." (Neuburger and Pagel, vol. II, p. 27.) Early in the seventeenth century Harvey discovered the circulation of the blood, and later in the same century Borelli worked out the mechanics of muscular movement. During the eighteenth century John Hunter in England, Haller in Germany, and Vicq d' Azyr in France advanced the study of comparative physiological anatomy and gave an impetus to the study of physiology which resulted, during the nineteenth, in its becoming an independent science.¹² The great discovery by the anatomist Bell, about a century ago, that the nerve fibres which serve to conduct nerve impulses into the **central nervous system** are other than those which serve to conduct impulses from the central organs to the muscles, was the first step in a definite study of localization of function in the nervous system. Since this discovery wonderful progress has been made in unravelling some of the mysteries of structure both of the central and the peripheral nervous systems.

Pathological anatomy, like physiology, has long since become an independent science. When bodies began to be frequently dissected it was discovered that many diseases are intimately bound

up with alterations in organic structure. The first to carry out an extensive study of diseased organs was Morgagni. (1682-1771).

Desire to penetrate deeper into structure than the unaided vision can go, led Eustachius, the great contemporary of Vesalius, to the use of simple lenses. But it was not until the further perfection of these and the invention of the compound microscope by Janssen and its improvement by Drebbel and Hooke, that microscopic anatomy began to make active progress. With the foundation of this the names of Hooke and Grew, of Leeuwenhoek, Malpighi and Swammerdam are imperishably associated. Malpighi was the first to extend the study systematically to animal tissues, Malpighi and Grew to that of plants. The blood capillaries and blood corpuscles were discovered and much new insight was gained concerning the true nature of glandular and other structures.

Meanwhile great advances were made in anatomical technique, among the most important of which may be mentioned the injection of blood vessels with melted wax by Swammerdam, which led to many discoveries concerning the distribution of these vessels; and the injection of fluids into the blood vessels, which made it possible to preserve anatomical material for slow, careful, minute dissection, necessary for exact study of structure.

At the end of the eighteenth century the next great step in advance was made by the brilliant French investigator, Bichat, who definitely formulated the conception of elementary tissues out of which, variously interwoven, all the organs of the body are composed and in the vital activities of which organic processes have their seat. Bichat disdained the use of the microscope, at that time an imperfect instrument, and invented various methods of distinguishing different tissues with the naked eye.

Bichat arrived, however, at but an imperfect conception of the tissues. The application of the improved compound microscope to the study of the tissues of growing plants and developing animals, led, after his death, to the discovery of new elements of structure in animal tissues and to a clearer conception of the nature of plant structure and finally to the formulation of the theory,

by Schleiden and Schwann, that the bodies of all organisms, both animals and plants, are composed of units of living matter, termed cells, and the products of the activities of these cells. Much study, especially in Germany, since 1840, has been directed toward the determination of the essential features of the cells and the tissues of animals and plants. The introduction of the cell doctrine into pathology and medicine by Virchow in 1855 has led to results of great practical value and has made the microscope indispensable to the physician. A complicated technique for preparing tissues from microscopic examination has been developed.

With the development of the microscopic study of the tissues and cells, the science of embryology has been closely associated. Aristotle, Galen, Fabricius (a pupil of Vesalius), Harvey, Malpighi, and other investigators, had studied the development of organisms prior to the eighteenth century, and during that century Haller, Bonnet, and others somewhat advanced the subject. Toward the end of the century some true insight was gained by Wolff into the nature of the early development of the hen's egg. Early in the nineteenth century this knowledge was much extended by von Baer and others. After the compound microscope came into extensive use, the ovum was found to be a single cell, fertilization was found to be due to the union of two cells representing respectively male and female elements. The complex structure of the higher organisms was found to arise from the cleavage of the fertilized ovum and the subsequent multiplication by division of the cells thus derived and their differentiation into various tissues.

A considerable share of the attention of productive anatomists for over half a century has been devoted to a study of the development of the general form and the differentiation of the organs and tissues of various organisms. The simpler conditions residing in the embryo have served to bring to light many essential facts of structure not easily to be made out amid the complex relations characteristic of the adult. W. His was a great leader in this field of study. (See F. Mall, *American Journal of Anatomy*, 1905.)

Of late years attention has been turned more and more to an experimental study of the conditions of organic development and

tissue differentiation. These studies have been conducted, on the one hand, largely by surgeons on man and the higher mammals in order to determine conditions of wound healing, tissue regeneration and the correlative dependence of part on part; on the other hand by anatomists and physiologists, zoologists and botanists, on plants, the lower animals, and on embryos, in order to gain insight into the laws of organic development.

While anatomy, during the past four centuries, has been developing in the interests of medicine and physiology along the various lines of descriptive anatomy, comparative physiological anatomy, histology, cytology, embryology, histogenesis, and experimental morphology, it has during the past century likewise received a great development from another standpoint.

The growing interest in animals and plants, which began about the time of Vesalius, led on the one hand to some study of the structure of the lower organisms and on the other to the discovery of so many different species that naturalists were forced to attempt systematic classification. It was eventually found that structure is the most satisfactory basis for the purpose. The study of anatomy from the standpoint of the similarities and differences in structures typical of various groups of organisms, has given rise to modern morphology. Cuvier extensively introduced the study of fossil forms and von Baer that of embryology into this field of study. It was discovered that a certain similarity exists between the successive stages of structural differentiation through which one of the more complex organisms passes during embryological development, the structure of organisms which paleontology has shown successively to have peopled the earth, and living organisms, arranged in a series, from the simplest to the most complex. Darwin's theory of evolution through natural selection led to a general belief in the genetic relationship of living things, those morphologically similar being most intimately related, and added new interest to this aspect of anatomical study.

The renewed impulse thus given to the study of structure and the simultaneous impulse given to the study of physiology by physics and chemistry, led not only to the formation of separate departments of physiology and anatomy, but also for a time to an unfortunate divorce between these two co-ordinate subjects.

Some morphologists went so far as to assert that anatomy in its physiological aspects should be left to the physiologist and that anatomists should concern themselves with the pure laws of structure. A large proportion of zoologists devoted themselves to a study of the comparative anatomy of dead animals and fossil forms and paid comparatively little attention to the relation of structure to function. But the development of experimental morphology on the one hand and the study of structural variation upon the other, has, during the past twenty years, led once more to the recognition of the value in biological investigation of keeping ever in mind the inseparable union of structure and function, form and environment.¹³

On human anatomy the morphological aspect of anatomy has had a marked influence by leading first to a study of the structures characteristic of different races of mankind, and then to a study of the variation in structure which different individuals show, and the nature and frequency of these variations.

Aside from the physiological and morphological points of view, human anatomy has been highly developed in its practical applications to medicine, surgery, and the fine arts.

ANATOMY IN AMERICA.

If now we turn to America we find until comparatively recently but few contributions to anatomy. In Europe as we have seen, the science arose in part from those interested primarily in the problems of medicine, in part from those devoted to the study of animals and plants. It is therefore of interest to trace the progress of anatomy in this country, first, in its relations to medicine, then to zoology and botany.

ANATOMY IN MEDICAL SCHOOLS.

The earliest medical schools founded in this country were established immediately before the Revolution by men who had been pupils of the great English anatomists, John and William Hunter in London, and of the Monros, at Edinburgh. A short course of didactic lectures and opportunity for dissection constituted the essential features of the curriculum. For a hundred years the

general standards of medical education rather declined than advanced. Dissecting served more to illustrate the text book studied for the sake of a quiz than to offer training in manual dexterity and in observation. The professors of anatomy were usually more engrossed in teaching authoratively and in the practice of medicine than in the advance of the science.¹⁴

Yet we owe a great debt to the men who in spite of popular ignorance and prejudice introduced and extended the study of human anatomy in this country. Thanks to the zeal of these men, often indeed amidst the greatest difficulties, practical anatomy was maintained in the better medical schools for a century before laboratories became a general part of our educational system. Thanks also to these early leaders state laws have been passed so framed as to furnish an adequate supply of material for this most fundamental of medical studies.¹⁵

Many of the teachers were men of character and force. A few, especially at the Philadelphia School of Anatomy and the University of Pennsylvania, were highly gifted men with scientific ideals.¹⁶ But the prevailing traditions concerning anatomy and anatomical instruction, the placing of undue emphasis on didactic teaching and on memorizing, hindered their work. These traditions still serve to hinder the general progress of the subject in this country. (See F. P. Mall, *Johns Hopkins Bulletin*, Jan. 1905.)

Microscopic anatomy was long neglected in most institutions and then was generally introduced as an aid to pathology and not as an essential branch of anatomy.¹⁷ Embryology is still inadequately treated in all but a very few institutions. The first good course in microscopic neurology given in a medical school in this country was that offered at the Johns Hopkins University in 1894.

On the whole American anatomy of the 19th century was essentially a diluted copy of the English anatomy of the 18th. Just as our earlier literary colleges were most of them modelled after the English colleges so our medical schools were more or less like the English schools. In spite of the friendship formed between France and the United States after the war of the Rebellion French influence never made itself seriously felt in our system of medical education. The works of Bichat were translated into

English and published in America early in the 19th century. Later, in the time of Louis, many Americans went to Paris for a medical education and some of them became distinguished physicians. Some slight stimulus to physiological experimentation was occasionally to be seen in America as a result of the great activity in France started by Magendie and Claude Bernard. But the English influence of the 18th century prevailed in American medical education until, in the latter half of the 19th century, men trained in Germany began to return to America filled with enthusiasm for the basal sciences.

Reform in medical education in America was inaugurated at Harvard in 1871 by President Eliot.¹⁸ The entrance requirements were raised, the curriculum was lengthened and graded, the basal sciences (anatomy, histology and embryology, physiology, chemistry, and pathology, and more recently, bacteriology and pharmacology) were placed in the first half of the course, laboratories¹⁹ were provided, and men scientifically trained were appointed to take charge of them.²⁰ Facilities for clinical instruction were likewise improved.

The reform thus inaugurated at Harvard led at first to a loss in the number of students and to a decrease in income, but soon the tide turned, public spirited citizens gave liberal sums of money to the school, and the better training there offered led to rapid growth. Other institutions have followed the example of Harvard and other university presidents have followed the lead of President Eliot, in demanding higher standards in medical education. The need of funds for laboratory courses and the desire for prestige, have led the faculties in charge of the medical schools to submit to some loss of control. Schools not connected with universities have followed so far as possible the lead of those thus connected, although often the improvements have been more apparent than real.

A most distinct advance in medical education in America was made when the Johns Hopkins University opened its medical department in 1893. Unusual opportunities were offered by the special endowment of the school; by its intimate connection on the one hand with a university which for fifteen years had supported advanced study and research in various sciences, including some

of those sciences most nearly related to medicine, and on the other, with a hospital richly endowed with special view to medical instruction; and by its faculty, selected from the country at large and solely from the standpoint of personal merit. Although in the better schools at that time merely a high school education was required for entrance, at the Johns Hopkins a degree was required from a college or scientific school in which a certain amount of biology, chemistry, and physics, French, German, and Latin had been studied, and, although in no school at that time were four years of medical study required, this standard was set up at the new school. But the chief service which the Johns Hopkins University has rendered to medicine in this country is the impulse which it has given to investigation and research in the medical sciences. Increased endowments and increased state support have enabled other institutions likewise to aid in this advance.²¹

Although the traditions hanging over anatomy have served in many ways to keep it from developing as rapidly as those basal sciences which have been more recently introduced into the American medical schools, still in the anatomical departments of some institutions notable advances have been made both in methods of instruction and in scientific activity.²²

Important contributions to anatomy have also been made from the pathological and physiological laboratories of medical schools and by clinicians.²³

BIOLOGICAL ASPECT OF ANATOMY.

Turning now to the biological aspect of anatomy in America we find that the study of the habits and distribution, and the features of color, form and structure characteristic of various species of animals and plants, living and extinct, began in this country early during the colonial days and has since had much support from individuals and from various States and the National Government.²⁴ Its chief monuments are to be found in the museums of the Philadelphia Academy, the Boston Society of Natural History, the New York State Museum, the Museum of Comparative Zoology at Cambridge, the Peabody Museum at Yale, the National Museum at Washington, the American Museum at New

York, the Field Columbian Museum at Chicago, the Carnegie Museum at Pittsburgh, and many other museums scattered throughout the country; and in the publications of these museums, of various learned societies, and of the State and National governments.

Productive study of the internal structure and of the physiology of plants and animals began in this country much later. Scholarly study of organic structure began with Jeffries Wyman,²⁵ and was extended by him and by Agassiz²⁶ at the Lawrence Scientific School established at Cambridge in 1847. Here good biological laboratory methods were utilized for the first time in America. For the last twenty years the anatomical laboratories at Cambridge have been in charge of E. L. Mark, whose great ability as an inspirer of investigation has lately been attested by a beautiful memorial volume of contributions from his pupils.²⁷

Among the pupils of Agassiz who have contributed especially to the subject of animal structure may be mentioned A. Agassiz, W. K. Brooks, A. S. Packard, and B. G. Wilder.²⁸ The majority of Agassiz's pupils, however, have paid attention rather to systematic zoology than to comparative anatomy, although many have contributed papers dealing with comparative anatomy in its relations to systematic zoology.

At Yale,²⁹ Princeton,³⁰ the University of Pennsylvania,³¹ the Johns Hopkins, and other institutions, departments of biology were established in the seventies. Of these the Johns Hopkins did the most to further the advance of biology because of the support which it gave to advanced and graduate work.³² At this period also many Americans began to go to the German universities for the sake of biological study. Trained men thus became available for university and college positions and the teaching of biology has gradually passed from the hands of jacks-of-all-trades into those of specialists.³³

In a number of universities the biological departments have been so extended in recent years as to embrace the subjects included in the first two years of the medical curriculum of the leading medical schools. This is of advantage because it gives breadth to biology as a science and depth to the training offered students preparing to study medicine.³⁴

In addition to the facilities for anatomical study offered in the medical and biological departments of various universities, marine and lake laboratories,³⁵ museums,³⁶ and other institutions offer opportunities for research. The progress of anatomy in recent years in America has also been much furthered by the establishment of societies,³⁷ and journals,³⁸ devoted to it and kindred subjects.

AMERICAN CONTRIBUTORS.

The increasing interest in anatomy in America as well as the increased foreign interest in American anatomy may be judged from the fact that in Schwalbe's *Jahresberichte* for the years 1872-1881 I find the names of but 30 American contributors to anatomy; for 1882-1891, about 60; for 1892-1901, nearly 400; and for the one year, 1902, about 120 Americans.

There has been a general increase in the number of workers in all civilized countries but the increase has been unusually rapid in America. The general index of Schwalbe's *Jahresberichte* for the years 1872-1881 gives about 5,000 names of anatomists and physiologists. It may be estimated that at least 3,000 persons contributed papers on anatomy during this period. American workers thus constituted about one per cent. of the world's productive workers during that decade. For the decade 1882-1891 there are about 8,500 names in the general index of Schwalbe's *Jahresberichte* of which about 5,000 may be estimated as those of contributors to anatomy. For this period the sixty Americans contributors to the subject therefore constitute about 1.2 per cent. of the total number. For the decade 1892-1901 the names of about 10,000 persons are indexed. The 400 American contributors thus form about 4 per cent. of the total number. For the one year 1902 about 2,500 names are catalogued of which about 120 or nearly 5 per cent. were those of Americans.

While the figures mentioned are only approximate estimates based upon a single source of information, Schwalbe's *Jahresberichte*, they indicate a gratifying increasing interest in anatomy in this country. Yet when one considers the size of the country and the fact that probably \$750,000 or more is spent each year in medical schools and biological departments on the

subject, it may readily be seen that in mere quantity we should do more than 5 per cent. of the world's work in this field. In quality I fear we could scarcely claim to do that much. A large number of the American contributors in the above table have written papers of small value on cases of abnormal development and similar topics.

From 1872 to 1881 the most productive American anatomists, judging from the space devoted to them in Schwalbe's *Jahresberichte*, were, E. D. Cope and O. C. Marsh in paleontology, A. Agassiz, H. Allen and J. Leidy in comparative anatomy, C. S. Minot in embryology, and T. Dwight in human anatomy. During the next decade, 1882-1891, the most productive men were G. Baur, E. D. Cope, O. C. Marsh, J. Leidy, and W. B. Scott in paleontology; H. Allen, H. Ayers, J. S. Kingsley, H. F. Osborn, and R. W. Shufeldt in comparative anatomy; H. Ayers, W. K. Brooks, S. H. Gage, F. Mall, C. S. Minot, J. A. Ryder, and C. O. Whitman in histology and embryology; H. H. Donaldson, E. C. Spitzka, M. A. Starr, and B. Wilder in neurology; F. Baker, J. D. Bryant, and T. Dwight in human anatomy. During the decade 1892-1901 E. D. Cope, J. Leidy, H. Allen, and J. A. Ryder were checked in the midst of scientific activity by death. The other workers of the preceding decade continued productive during this and in addition the names of several other active investigators appear:

In paleontology, B. Dean, C. R. Eastman, J. B. Hatcher, F. A. Lucas and H. F. Osborn; in comparative anatomy, E. P. Allis, C. H. Eigenmann, H. H. Field, O. P. Hay, W. S. Miller, and G. H. Parker; in histology and embryology, R. G. Harrison, G. C. Huber, J. B. MacCallum; in neurology, H. J. Berkeley, P. A. Fish, C. J. Herrick, A. Meyer, W. C. Spiller, and E. A. Spitzka; in human anatomy and physical anthropology, G. A. Dorsey, and A. Hrdlicka; and in invertebrate embryology and experimental morphology E. G. Conklin, C. B. Davenport, F. R. Lillie, J. Loeb, L. Loeb, T. H. Morgan, and E. B. Wilson.

AMERICAN CONTRIBUTIONS.

- From this brief review of the development of the interest in anatomy, the facilities for its advancement, and of the names of

leading investigators we may turn to a consideration of the contributions made to the science in this country.

I shall not attempt, of course, to review all the contributions made to the science of organic structure by Americans. Thousands of papers have been published dealing with the form, structure and the development of various species of animals and plants, living and fossil, the value of which can be adequately judged only by specialists in different fields of zoology and botany. I shall try merely to call attention to some of the more recent work in fields that should be covered by a department of anatomy designed to play a part in medical education. These fields should be, I think, special human anatomy, in all its phases, from embryology to physical anthropology; the comparative anatomy of vertebrates, and more especially of mammals; neurology; histology; embryology; general morphology; and the technique of anatomical investigation and expression, including artistic anatomy.

*I. Special human anatomy.*³⁹—Generations of gifted investigators, teachers and writers, in the three centuries and a half that have elapsed since the death of Vesalius, have so perfected the subject of descriptive systematic and topographical human anatomy that few sciences can boast of text-books and hand-books, atlases and models so exact and satisfactory. There are still open, however, several fruitful fields of investigation in this branch, among which may be mentioned the statistical study of structural variation in relation to race, sex, age and social conditions, and certain fields of physiological and special topographical anatomy.

The value of statistical study of variation has long been recognized in physical anthropology and numerous studies have been made of variation in the relative proportion of length to width of the skull and similar simple external structural features, in order to determine racial and sexual characteristics. In America pioneer work in physical anthropology was done in the first half of the nineteenth century by S. G. Morton of Philadelphia, of whose collection of human skulls Agassiz wrote (Louis Agassiz, by E. C. Agassiz. 1885. p. 417): "Dr. Morton's unique collection of

human skulls is also to be found in Philadelphia. Imagine a series of six hundred skulls, mostly Indian, of all tribes who now inhabit or formerly inhabited America. Nothing like it exists elsewhere. This collection alone is worth a journey to America." Pioneer work was likewise done by Dr. D. A. Sargent who exhibited at the Chicago world's fair in 1893 a composite statue of the American college boy and one of the American college girl, each based on measurements of a large number of individuals. H. H. Wilder has recently contributed a most valuable paper on duplicate twins and double monsters in which he has shown that even the finger prints of duplicate twins are duplicated.

Recently attention has been turned toward variation in internal structure, and embryology and comparative anatomy have been called upon for their invaluable aid.

In this country valuable contributions to skeletal variation have been made by Boas, Dorsey, Dwight, Hrdlicka and others. For the layman, who has given up belief in a too literal interpretation of Eve's origin, it may not be uninteresting to learn that $2\frac{1}{2}$ per cent. of people have only eleven ribs and $2\frac{1}{2}$ per cent. have thirteen, as I have recently found from a statistical study, based upon my own observation and those of several other investigators. I have likewise been able to show by a statistical study of variation in the spinal column of embryos that variation there occurs with about the same frequency as in the adult.

Statistical studies have likewise been extended in this country to the blood vessels and peripheral nerves. Thus Walsch some years ago made an extended study of variations in the brachial nerve-plexus and more recently A. W. Elting and I have studied variation in the lumbo-sacral plexus in relation to side of body, age, sex and race. In this instance no very marked features were found to be characteristic of these different conditions but Bean has found that the branches of the subclavian artery in the infant differ from those of the adult.

Most statistical studies on internal structural variation have been confined to a given organic system, i. e. a part of the skeleton, a group of blood vessels or a set of peripheral nerves. In the studies on the lumbo-sacral plexus, mentioned above, we attempted a co-ordinate investigation of skeletal variation and found that

there is an agreement, though imperfect, between variation in the spinal nerves which supply the limb and variations in the spinal column with respect to the position of the limb-skeleton. These and subsequent studies have likewise shown that there are areas of the body in which structural variation is frequent and extensive and other areas in which it is less common and less in amount. Thus variation at the junction of the thoracic with the lumbar or lumbar with the sacral region of the spinal column is more marked than in the central area of the thoracic, lumbar or sacral regions, and variation in the distribution of the peripheral cutaneous nerves is especially prominent in the region of the junction of the limbs with the body wall.

A great value of this general line of work is that it may be carried on in the dissecting rooms and thus while the students are aided by a consequent quickening of their attention their arduous studies may to some degree be utilized for science.

Special study has been devoted to variation in the form of the brain in relation to the mental activity of the individual. Donaldson's study of the brain of the talented blind and deaf Laura Bridgeman was an important contribution. B. G. Wilder, at Cornell, has been an enthusiastic leader in the attempt to get brilliant individuals to bequeath their brains for special study after death and has accumulated quite a collection at Ithaca. Some of these brains he has already described at length. E. A. Spitzka is engaged upon an extended study of the comparative anatomy of the brains of individuals of various races and of various classes of society and has made most distinct advances in this line of work.

Some years ago a number of prominent scientists, William Pepper, Harrison Allen, J. Leidy, F. X. Dercum, and E. C. Spitzka, formed an association the object of which was to get the members to pledge their brains for subsequent anatomical study. E. D. Cope, A. J. Parker and Philip Leidy afterwards joined the society. At the death of six of these gentlemen their brains were deposited in the Wistar Institute at Philadelphia. For some time Dr. E. A. Spitzka, whose previous studies on the relation between variation in brain morphology and mental and social conditions has especially fitted him for the task, has been engaged upon a comparative study of these brains. He has discovered

that the corpus callosum, the chief fibre mass connecting the two halves of the cerebrum, is much better developed in individuals with a high mental capacity than in individuals of average ability. R. B. Dean, working in Professor Mall's laboratory, has discovered a distinct difference in shape between the brain of the negro and that of the Caucasian.

Real contributions to the teaching of human anatomy and to the care and preservation of material for the dissecting room have likewise been made by Americans. F. D. Weisse, professor of anatomy at the University of New York, published in 1886 a dissector's guide (*Practical Human Anatomy*) thoroughly original in design and of great value, but unfortunately not appreciated. At Columbia, G. H. Huntington has organized a splendid museum of comparative vertebrate anatomy as an aid to the study of human anatomy and has devised many useful methods for demonstrating special preparations to students engaged in dissection. Professor Huntington was the first to do away with didactic lectures to beginning students. At The Johns Hopkins University F. P. Mall has introduced the use of small dissecting rooms where two or three groups of students may dissect more quietly than in the old-fashioned large dissecting room, has devised several useful aids to dissection, has done away entirely with formal didactic lectures on descriptive anatomy and has encouraged the students to dissect carefully and thoroughly with book in hand. (See F. P. Mall, *Anatomical Courses at the J. H. U.* Bulletin of the Johns Hopkins Hospital, May-June, 1896.) The use of charts to serve as guides to the student in his drawing of dissected parts and for recording data gathered for scientific statistical study, and the use of clay modelling in the study of the bones and other parts of the body were also introduced in Professor Mall's laboratory, and a special study room has been developed where students may study at leisure frozen sections of the body, dissected parts and special preparations. These various aids to teaching have to a greater or less extent been introduced into other laboratories in America. Improvements in methods of instruction have been likewise inaugurated in several other laboratories.

The use of cold storage for the preservation of anatomical material is an American contribution. The first cold storage plant

to be used to preserve dissecting material was installed at Columbia University, New York. Similar plants have since been established in a large number of medical schools. While not necessary when but a small amount of material must be kept on hand, these plants are of value where a large amount of material must be stored. (See A. T. Kerr, *The Johns Hopkins Bulletin* XII, 1901. F. P. Mall, *ibid.*, 1905.)

To the subject of physiological human anatomy comparatively few contributions have been made by Americans. Original work of great value, however, was done by Muybridge, who studied by means of photography the movements not only of some of the domestic animals but also of man and brought to light many new facts.

A number of American investigators have studied the distribution of the peripheral nerves in man from the standpoint of function. Important contributions to this subject have been made by M. Allen Starr, L. F. Barker, and Harvey Cushing.

Americans have made a considerable number of contributions to the topographical anatomy of special regions which are of surgical importance. In this connection should be mentioned the work of M. Broedel who has done so much to raise the standards of anatomical illustration in this country.

A department of anatomy undoubtedly should have a professor of artistic anatomy on the one hand to offer courses to artists seeking knowledge of organic structure, and on the other hand to train investigators in the technique of illustration.

The study of special human anatomy has been extended from the gross to the minute anatomy of the body. While knowledge of the specific nature of all of the human tissues is of special interest to pathologists and clinicians who desire to compare normal with diseased structures, the greatest interest in the field of special human microscopic anatomy and histology has been shown in the nervous system.

H. C. Berkley and A. Meyer, among other Americans, have contributed to the knowledge of the structure of the central "psychical" nerve cells of man. F. R. Sabin's reconstruction of the medulla of the child is a widely known important contribution to brain anatomy. The work done by Ingebert in Professor

Donaldson's laboratory at Chicago in the determination of the number of nerve fibres in the spinal nerves of man and that of Helen Thompson in the determination of the number of nerve cells in the human cortex, likewise merit special mention.

Accurate descriptive anatomy of human embryos is of importance to human anatomy because the simpler conditions existing in the embryo tend to explain the essential amidst the complexity of adult anatomy. Thus Mall's studies of the development of the intestine have enabled him to point out a regularity in the position of the intestinal folds in the adult, a regularity not previously recognized. Professor Mall has at Baltimore probably the most complete existing collection of human embryos prepared for microscopic study. He has done much to introduce into this country the methods of reconstruction by means of wax plates developed by Born and His in Germany. In his laboratory plastic reconstruction of embryonic structures has been extended by Mall, Lewis, Streeter and Bardeen from the field of the central nervous system and viscera studied by Born, His, and others, to the peripheral nervous, muscular, and skeletal structures. Over sixty papers based upon his collection have been published.

Special mention should here be made of the pioneer work of Professor Mall in the study of pathological human embryos, a work of fundamental importance as a basis for a scientific teratology.

Having now briefly treated of some modern aspects of special human anatomy we may turn to a consideration of comparative organic anatomy.

*II. Comparative organic anatomy.*⁴⁰—Primarily, we have seen, the study of comparative anatomy arose from those interested in physiological problems who turned to animals for knowledge not readily obtained from man. Later the desire to base the classification of animals and plants upon physical characteristics led to the development of ideas of type structure and of a pure science of morphology based directly upon comparative study of structure without regard to function. Of late the tendency is fortunately once more to study structures from their two-fold aspect of form and function. In the study of the organs we may compare

the gross general structure of a given organ as it appears in a series of animals or we may seek to determine the essential units of structure out of which an organ characteristic of many related animals is composed.

The majority of American biological investigators have, however, until recently been interested in structure rather from the standpoint of form characteristics of use in the systematic classification of animals than in the comparative anatomy of the organs as a basis of a rational comparative physiological anatomy. The skeleton and teeth, because of their value in systematic classification and in paleontology, have thus received the bulk of attention. L. Agassiz, G. Baur, E. D. Cope, J. Leidy, O. C. Marsh, H. F. Osborn, W. B. Scott, R. W. Shufeldt, and S. W. Williston are among those who have contributed most to this subject. E. D. Cope has been called by a leading American biologist, the foremost anatomist since Cuvier. J. K. Thatcher's theory of the comparative anatomy and development of the limbs is one of the most highly valued of American contributions to morphology.

There is a growing interest in the comparative anatomy of systems of organs other than the skeletal. Among the leaders in this study may be mentioned S. H. Gage, G. S. Huntington, J. S. Kingsley, J. P. MacMurrich, C. F. W. McClure, W. S. Miller and C. S. Minot. The work on the comparative anatomy of the nervous system I shall speak of later.

The comparative study of organic-units is of more recent development than that of the organs themselves. In some structures, like the voluntary muscles, the individual cells seem to be the only definite units of structure. In other organs the component tissue may be resolved into a vast number of more or less distinct units, each of which in turn is composed of cells arranged with definite relations to vascular and other structures. Many glands, like the liver and pancreas, may readily be seen to be thus made up, while in other organs, like the spleen, it is more different to recognize the units of structure. F. P. Mall has been a leader in the investigation of these structural units. J. L. Flint has done much to extend the knowledge of their supporting framework. G. C. Huber has added most materially to the knowledge of the structure of the kidney and other glands. Warthin has discov-

ered that the lymph nodes may be resolved into two classes with intermediary forms, the true lymph glands, and the hemolymph glands. One of the most important contributions yet made in this field is that of Professor Miller, who was the first definitely to determine the true nature of the organ units of the lung.

*III. Histology.*⁴¹—The study of the tissues is closely associated with that of organology. To this subject Americans have made several important contributions. Of these perhaps the most important is the discovery by F. P. Mall of a new kind of fibrous supporting tissue which he called reticulum. The discovery of an element of this kind in anatomy is equivalent to the discovery of a new chemical element in chemistry. Previously only two kinds of fibrous connective tissue were recognized, the white non-elastic, and the yellow elastic. Recently by a process of differential staining Mallory has added a fourth to this group. Kyes, Flint, and Mall have done much to extend our knowledge of reticulum as the supporting framework of many glands. R. R. Bensley has done beautiful work in the study of the nature of the epithelium of the alimentary canal; Chittenden, Eycleshymer, Gage, Huber, and others have added to the knowledge of muscle, Minot and Mall to that of the blood vessels. Although in 1876 Packard could write that up till then no attention had been paid in biological monographs to histology, today the work done in America certainly compares favorably with that done in Europe.

An important part in histology is played by methods of technique used in preparing tissues for microscopic examination. Minot has contributed largely to this by the development of microtomes for cutting thin sections, and Delafield, Van Giesen, and Mallory by the invention of several important methods of staining. Mallory introduced the use of carbon dioxide as a means of freezing tissues for sectioning and Cullen the use of formaline for hardening frozen sections so that they may be stained.

R. R. Bensley and L. F. Barker have discovered useful micro-chemical methods for the determination of iron in the tissues. F. P. Mall has developed extensively the use of artificial digestion as a method of tissue differentiation.

*II'. Cytology.*⁴²—The importance of an understanding of the physical nature of the living units of organic structure has led to a special study of the cell. It is here that botanists and zoologists find themselves upon a common ground, because in the most essential features animal and vegetable cells are similar in structure. A great number of American investigators have contributed to the subject. Professor E. B. Wilson has written a text-book on "The Cell" that stands perhaps at the head of the books that have been written on that subject. The chief cytological studies have been carried out on the sex cells and on nerve cells, and hence we may pass on to a consideration of embryology and neurology.

*V. Embryology.*⁴³—Embryology has attracted a great number of modern American investigators. The contributions to the subject concern the formation of the sexual cells, the spermatozoa and the ova, the conjugation of these cells and the early stages of structural differentiation, the formation of the various organs of the embryo, and the accompanying development of the complex tissues of the adult from the simple tissues of the embryo.

It would be absurd here to try to enter into a description of the vast amount of work that has been done by Americans along these lines. The work done here compares favorably with that done in any other country. The first to develop active interest in modern methods of the study of vertebrate embryology in this country were C. S. Minot, J. Ryder, and C. O. Whitman. Minot has contributed one of the most important text-books on vertebrate embryology yet written, and has established at the Harvard Medical School the most complete existing collection of vertebrate embryos prepared for microscopic study. This collection has already served as the basis of many important contributions, and is likely to prove of the greatest value for many years to come. Among those who have charge of laboratories where the greatest amount of research in comparative embryology is being done may be mentioned C. O. Whitman and F. R. Lillie, Chicago; E. G. Conklin, Pennsylvania; G. C. Huber, Michigan; S. H. Gage, Cornell; F. P. Mall, Johns Hopkins; E. L. Mark and C. S. Minot, Harvard; J. S. Kingsley, Tufts; T. H. Morgan and E. B. Wilson, Columbia.

Of the more fundamental American work in the field of comparative vertebrate embryology mention may be made of that of Minot and Lee on the foetal membranes, of Minot and his pupils on the blood vessels, especially of his formulation of the conception of sinusoids, or vascular spaces which arise from the ingrowth of glandular tissues into blood vessels during embryonic development, of F. R. Sabin's work on the development of the lymphatics from the veins, of MacCallum's on the arrangement of the musculature of the heart, of Huber on the development of various glands, of Mall on the histogenesis of the connective tissues and of various organs, of Harrison on the histogenesis of the peripheral nerves, of MacCallum and Eycleshymer on the histogenesis of muscle and of W. S. Miller on the lungs.

*VI. Neurology.*⁴⁴—The predominating importance of the nervous system in the animal economy has led to so much special work on the gross and minute comparative anatomy and the physiology of the nervous system as to give rise to a special branch of science called neurology. In addition to the special study of the human nervous system, comparative studies on the gross and minute anatomy of the peripheral and central nervous systems and organs of special sense have been made by many Americans. Without attempting here to summarize these various contributions or their value, I shall merely call attention to some of the more important work of Americans. In L. F. Barker's "The Nervous System," (1899), full justice is done American workers.

H. D. Schmidt and A. J. Lanterman discovered the segments in the medullary sheath of the nerve fibre which are known by their names. E. A. Birge some twenty years ago pointed out the correspondence in number between the motor cells in a given segment of the spinal cord and the medullary fibres of the corresponding nerve root. In H. H. Donaldson's laboratory at Chicago statistical methods of determining the relations of nerve fibres to nerve cells and to various peripheral structures have brought to light many important facts. In this laboratory likewise valuable work is being done in the determination of the effects of starvation and similar factors on the development of the nervous system. In fishes and amphibia O. S. Strong, C. J.

Herrick, and J. B. Johnston have determined the morphological distribution in the cranial nerves of various component sets of nerve fibres each of which has specific functions to perform. H. C. Berkley was the first to apply successfully the Golgi method of impregnation to the study of nerve endings in the viscera; C. F. Hodge, once a member of the biological staff here, was the first to study the effect of fatigue on the nucleus of the nerve cell; G. C. Huber, one of the first to apply the newer methods of staining to nerve endings in muscle, and P. Sargent has opened up several interesting lines of work. Loeb's monograph on the physiology of the nervous system contains original theories concerning structure as well as function. Howell and Huber have contributed important papers on the regeneration of nerves. Mallory, Huber, Ingebert, and others have made additions to our knowledge of neuroglia. And so I might continue; but the list of American contributions to comparative neurology is too long for it to be possible to do justice to all in this discussion.

*III. Experimental morphology.*⁴⁵—Along with the descriptive study of embryological development there has grown up, largely within the past twenty years, a field of study of even more fascinating interest, the experimental study of the factors which determine form and tissue differentiation. In the study of the healing of wounds, surgeons have for ages had occasion to test the formative power of various parts of the human body. For over a century, biologists have been acquainted with the wonderful restorative powers possessed by certain of the lower organisms. But it was not until Pflüger and Roux, early in the eighties, published their experiments on the developing ovum of the frog, that the attention of zoologists was turned to the great value of accurate experimental study of the formative potentiality of organic structures. In the development of this field of work Americans have played a foremost part. Among them may be mentioned E. G. Conklin, C. B. Davenport, R. G. Harrison, F. R. Lillie, W. H. Lewis, J. Loeb, T. H. Morgan, and E. B. Wilson.

I can here merely mention a few of the directions which these experimental studies have taken.

First there has been an attempt to determine to what extent

formative potentialities are localized in the ovum, and it has been shown that while in some organisms definite areas of the ovum are capable of developing approximately merely the structures which would arise from them in normal development, small parts of the ova of other organisms are capable of giving rise to symmetrically perfect embryos. Thus a quarter of the ovum of a sea urchin, which under normal circumstances would give rise to a definite area of the body, may, if isolated under proper conditions, give rise to a complete larva one-fourth the normal adult size. Wilson, Morgan, Conklin, and Lillie have been among the leaders in this field of work. (See E. B. Wilson, *Science*, Feb. 24, 1905.)

Another line of study has been that of the regenerative capacity of the lower organisms and the internal and external factors concerned. Morgan has been a leader in the field and his monograph is a standard work. F. R. Lillie, F. Peebles, C. M. Child, H. W. Rand, and C. Zeleny, among others, have contributed extensively to the subject.

J. Loeb, who though a German by birth, is by adoption an American and in both inventiveness and intensity of application a truer American than many of his fellow workers, may be counted the most original biological investigator in America. Among the important contributions which he has made to experimental morphology may be mentioned his work on heteromorphosis or the phenomena which some organisms show of regenerating in place of lost parts new parts unlike those lost, a head in place of a tail for instance, and his well known discovery of artificial parthenogenesis brought about by altering the physical or chemical nature of the media surrounding unfertilized ova.

The effects of heat and light on development have been studied by Davenport, Loeb, Tower, Edwards, Greeley, and others; the effects of the Roentgen rays in checking development in ova and regeneration in organisms by Gilman, Baetjer, and Bardeen; and on the skin and other tissues of the higher organisms by Pusey and Caldwell and others.

Tadpoles have been much utilized for the experimental determination of the power of correlative differentiation in the embryo and of organs to develop in unusual situations. R. G. Har-

rison has shown that the sense organs of the lateral line and the musculature may develop independently of nerves; W. H. Lewis that if the rudiment of the optic vesicle be placed in some other region than the head it may stimulate the differentiation of a crystallin lens from the epithelium of that region. F. R. Lillie and F. Peebles have made important experiments on the effects of mutilation of parts in the developing chick. R. G. Harrison, W. H. Lewis, and T. H. Morgan have made interesting studies on the grafting of a part of the body of a tadpole of one species to that of another species.

In the higher organisms, such as the mammals, conditions of development preclude extensive mechanical experimentation on the developing embryo. After birth, although the powers of regeneration of complex organs like the arms or legs or head, characteristic of some invertebrates, is no longer found, there is a high capacity of regeneration of peripheral nerves, of blood vessels and of most of the tissues of the body. In many respects the best work that has yet been done on nerve regeneration is that of Howell and Huber. F. P. Mall has performed some fundamental experiments on the regeneration and regulation of the tissues of the intestine after section. L. Loeb has executed some important experiments on tissue transplantation. American surgeons have made numerous contributions to the subject of wound healing. But I have not at present time to enter further into details concerning this important line of work.

The effect of physiological activity on the structure of cells was inaugurated by C. F. Hodge's experiments on the effects of fatigue on nerve cells. P. K. Gilman has shown a similar effect on the nuclei of muscle cells.

VIII. Teratology. Experimental morphology is essentially experimental pathology since it is impossible to experiment on the living substance without subjecting it to abnormal conditions. In the great laboratory which nature conducts very abnormal forms, monstrosities, are not infrequently produced. The study of these organisms that have failed to develop in a normal manner, often throws light on the factors at play in normal development. The study of teratology is therefore quite as important to the student of normal as to the student of pathological anatomy.

We have many descriptions of isolated instances of malformation of animals in this country although no American until recently has handled the subject in a broad spirit. H. H. Wilder is at present making most valuable studies of double monsters.

*IX. Variation and heredity.*⁴⁶—Lastly I wish to touch briefly upon a field of biological investigation which in many aspects lies within the province of the anatomist. In speaking of human anatomy I showed that a most important line of work is the study of structural variation in races and individuals. It is well known that certain structural peculiarities like six fingers, or functionless ears* tend to run in families. Statistical studies of inheritance of characteristic structures and functions, first carried out on a large scale by Galton, have been extended from man to the lower animals and plants, and have thrown much new light on organic development. One of the foremost investigators in this field is C. B. Davenport, who, through his own work and that which he has inspired in others, has brought large and fertile areas under cultivation. The experimental study of inheritance through carefully controlled breeding experiments has likewise received notable contributions from American investigators, among the foremost of whom stand C. O. Whitman, C. B. Davenport, and W. E. Castle. The effects of hybridization on the germ cells have been followed by M. P. Guyer, W. H. Moenkhaus, and W. S. Sutton.

My time is growing short. I have but imperfectly sketched various fields of work, from simple descriptive human anatomy to experimental studies of inheritance, which properly come within the province of anatomy and toward the cultivation of which an anatomical laboratory run on a broad scale should contribute. Anatomy like all the other sciences is simultaneously advanced by workers in many countries. In singling out some of the contributions made here I have merely wished to show that American workers constitute an important factor in the present progress of the science.

In this progress, work done in the laboratories at this univer-

*The work of Alex. G. Bell on the inheritance of deafness is one of the best statistical biological studies that has ever appeared.

sity has constituted a distinct element. We hope to see the part played by Wisconsin a yet greater one; the laboratories and facilities of the new department become a center of attraction for those desirous of doing advanced work in anatomy; museums and a library developed that may be looked to with confidence by anyone desirous of the most accurate information concerning organic structure; courses of instruction maintained capable of developing the power of accurate observation, deep insight and broad grasp. In these aims we are sure of a stimulating union with the other scientific departments of the university.

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1, (p. 87). BIOLOGY AT WISCONSIN.

The development of the study of the biological sciences at the University of Wisconsin is indicative of the general progress in this field during the past thirty years in this country. Prior to 1875 didactic lectures had been given in "natural history," and for a time in physiology and hygiene, and in comparative anatomy and entomology. In 1875 E. A. Birge became instructor in zoology and offered laboratory work. In 1877 a "Science Hall" was built at a cost of \$80,000. In this building the various sciences were accommodated and laboratory instruction was offered in zoology and botany. These two departments grew rapidly. In 1881 courses in histology and embryology were begun. In 1884 the overcrowded "Science Hall" burned and in 1887 the present "Science Hall" together with special buildings for chemistry, a heating plant, and machine shops, were finished at a total cost of \$345,000. In the new building zoology and botany were given much better quarters and better equipment than of old, an excellent course preparatory to the study of medicine was established, and opportunity for advanced work and research was offered. Since 1892, W. S. Miller has done much to develop vertebrate anatomy. Bacteriology, at first given by Professor Birge, became in 1893 a separate department under the charge of Professor Russell.

The rapid growth of the scientific, as well as of the other departments of the university, soon caused the new Science Hall to be over-crowded. Some relief was felt when in 1901 the College of Engineering, which up to this time had been housed in Science Hall, was provided with a special building. In 1902-3 the spacious attic of Science Hall was remodelled in such a way as to provide quarters for a botanical green house and for an attractive set of laboratories for human anatomy, and in 1904 a department of anatomy was established. The building is much over-crowded, however, and soon provision must be made for housing elsewhere one or more of the six departments, physics, geology, botany, zoology, anatomy and psychology, now quartered in it, as well as for the department of physiology soon to be established.

Thirty years ago one man, R. H. Brown, was the only instructor in natural history. Twenty years ago Professor E. A. Birge was the only instructor in zoology, and Professor W. Trelease, the only instructor in botany. Ten years ago there were two instructors in addition to

Professor Birge in the zoological department, Professor Barnes and L. S. Cheney were instructors in the botanical department, and H. L. Russell had charge of bacteriology. Today the following men are on the staffs of the biological departments of the university.

Zoology: Professor E. A. Birge, Assistant Professor W. S. Marshall, G. Wagner, C. T. Vorhies.

Anatomy: Professor C. R. Bardeen, Associate Professor W. S. Miller, Dr. B. M. Allen, Dr. F. Schmitter.

Botany: Professor R. A. Harper, Assistant Professor C. E. Allen, R. H. Denniston, W. G. Marquette, E. W. Olive, J. B. Overton, G. M. Reed, and Miss H. Sherman.

Bacteriology: Professor H. L. Russell, Assistant Professor W. D. Frost, E. G. Hastings.

In addition there are a number of other biologists connected with the school of agriculture.

2, (p. 87). DEFINITIONS OF ANATOMY.

"Anatomy, or the science of the structure of organized bodies." Owen, *Anatomy of Vertebrates*, London, 1866, Vol. I, p. 6.

"Anatomy, a science the province of which is to determine the construction, the form and the structure of organized bodies, i. e. of bodies which either are or have been living." W. Turner, *Encyclopaedia Britannica*, IX Edition.

"Anatomy is and remains the science of the structural parts of the organism and of the laws of their origin and transformation whether these structural parts are visible to the naked eye or only through the microscope." A. von Koelliker, *Die Aufgaben der Anatomische Institute*, Würzburg, 1884, p. 5.

3, (p. 88). UTIMATE NATURE OF LIVING SUBSTANCE.

"Our surest knowledge is confined in the main to structural relations, the form of the tissue elements with which the phenomena of consciousness are bound up, their mutual relations, their localizations in the brain. To trace the phenomena back to basal substances and forces is not possible; we know merely that the chemical substances present in the brain come into play; we surmise that these elements are united in the living brain into the most complicated bodies of our planet but at present we know only products of decomposition of the psychical substances; and thus the determinable boundaries of this

field of natural knowledge still lie in foggy distance." Flechsig, *Gehirn und Seele*, 1896, p. 11.

"What a living being is and what life is can scarcely be truly formulated in a short definition, only this may be said, that life rests in a special characteristic organization of matter and that with this organization furthermore special processes or functions are bound up such as are never found in lifeless nature." Hertwig, *Die Entwicklung der Biologie im 19. Jahrhundert*, Jena, 1900, p. 4.

"Undoubtedly these general considerations have their value in connection with problems with which we are dealing only in the thorough investigation of the components which serve to distinguish biological objects from chemical objects. We sum up this distinction ordinarily in the word *life*. If we inquire into the parts of this concept which may be recognized and measured we find the following to be true: Living beings in the first place are not stable, but on the contrary are stationary structures. Rapid changes take place in them of such a nature that gain and loss counterbalance one another so that the whole system experiences only slow changes (which are almost all periodic). Since all physical changes may be represented as displacements of different kinds of energy in space and time living organisms are characterized by the fact that they keep their condition of energy approximately constant in its nature and amount, while a constant current of various energies flows through their bodies. According to the general laws of energy this can take place only in such a way that the living organism takes up energy of a higher potential and gives it off at a lower potential. In the meantime the energy has been used for those transformations which make up the various activities of life, namely, movements, the production of heat, reproduction, etc." (Ostwald, W.: *The Relations of Biology and the Neighboring Sciences*, Univ. of Cal. Pubs., *Physiology*, Vol. I, No. 4, p. 24.)

"Living organisms are chemical machines, made up essentially of colloidal material, which possess the peculiarity of developing, preserving and reproducing themselves automatically." (J. Loeb, "Recent Development of Biology," Address, Congress of Arts and Science, St Louis, Science, Dec. 9, 1904.)

4, (p. 89). GREEK ANATOMY.

For details concerning the ancient Greek anatomy reference may be made to Neuburger and Pagal's "Handbuch der Geschichte der Medizin," Jena, 1902; Carus', "Geschichte der Zoologie," and to the numer-

ous other books which have been written on the history of zoology and medicine.

5, (p. 89). SALERNUM.

Vid. F. Merkel, *Verhandlung der Anatomische Gesellschaft*, IX, Basal, 1895.

One of the first steps in the revival of learning in Christian Europe was the growth of a great medical school at Salerno during the eleventh century and its definite organization in the twelfth. This school represents in a way the first of the modern universities. Roger II, in 1137, instituted the first state examinations in medicine. Even to practice surgery, which for many centuries after this was in most countries in the hands of barbers, a year's attendance at lectures on anatomy and surgery was required. At Salerno the medical student took a preliminary training of three years in logic and language, studied medicine and surgery for five years, then passed an examination and placed himself under some physician for practical training. Those acquainted with medical education will recognize at Salerno in the Europe of the dark ages, nearly a thousand years ago, a higher general standard than is found in many parts of the United States today. (See S. S. Laurie, *Rise of the Universities*.)

The school at Salerno represented a survival of what scientific medicine had managed to pass through the vicissitudes of Italy from the third to the twelfth centuries, although its history can by no means be clearly traced back of the tenth century. The earliest existing records show it to have been a civil, not a monastic institution. Jews were active in its management. Practical anatomy was conducted on the pig, which was deemed at that time most nearly of the lower animals to resemble man in internal structure. An anatomy of the pig was written there. During the twelfth century medicine was re-introduced from Moorish Spain into Christian Europe. The school at Salerno was greatly influenced by this movement and ultimately was crowded out by the establishment of rival schools at Montpellier, Naples, Bologna and other universities. But the pig remained the classical object for anatomical demonstration for over two centuries. Today it is once more assuming a position of dignity as a favorite object for research and instruction in mammalian embryology.

6, (p. 90). ANATOMY IN ITALY PREVIOUS TO VESALIUS.

During the fourteenth and fifteenth centuries help was gained from the painters and sculptors of the period, who were eager to learn the

nature of human structure from dissection and whose influence with the Church and State led to a powerful support from popes and princes which otherwise anatomy might not have enjoyed. Under Paul III (1534-49) a school for anatomy and botany was erected in Rome and a living for the prosector was guaranteed. Another source of aid came from the literary revival of this period and from the art of printing which did so much to make possible a comparison of texts. In the fourteenth century there are said to have been but nine books at Paris; in the fifteenth, eight hundred were published. The Arabic anatomies were compared with the original Greek, and Aristotle and Galen came into great favor. But the critical faculties developed by the study of texts led more and more to a study of nature, when the texts failed to agree, and thus to new knowledge. (Vid. Neuburger and Pagel, *Handbuch der Geschichte der Medicine*, Bd. II, *Einleitung*, where these ideas are developed at greater length.)

In the study of historical periods from the standpoint of an environment to the development of which thousands of great men have contributed earnest lives of self-devotion, it is difficult to prevent a feeling of personal superiority over those who lived before this development took place. And thus we of today are apt to smile at the childishness of men who for centuries taught imperfect ape and pig anatomy as that of man, whose ideas of the relation of structure to function have long since been outgrown, and who were wont, when descriptions read in their text-books failed to agree with structure seen, to apologize for the structure and deem book statement true. As for instance when it was pointed out to Sylvius that the human sternum is composed of three parts while Galen described it as composed of seven, Sylvius said that doubtless in the good old days of Galen when men were heroes the sternum was composed of seven bones but for modern degenerate man three sufficed. (Vid. Merkel, *Anatomische Gesellschaft*, 1895.) But like the human skeleton, human nature has remained much the same during at least all historical periods. Even today we find text-books called "human histology," "human embryology," and "human physiology," illustrated largely from lower animals, not always for the sake of comparison, but with the mistaken idea that such illustrations serve well enough to describe human structure and function; and much modern biological speculation is little better than the fumosities that escaped through Mondinus's skull. Here in America during the last half century Gray became such an authority on gross human anatomy that to many the two terms have seemed synonymous and thousands of students, lacking confidence in their power to see for themselves, have turned away from apparent imperfections

actually found in human structure to get what they are sure must be the real truth from Gray.

7, (p. 90). VESALIUS.

Roth's biography of Andreas Vesalius, 1892, gives a most interesting account of Vesalius and of his influence. Of the predecessors of Vesalius, Leonardo da Vinci seems to have been the first to make accurate anatomical illustrations and some historians consider him the true founder of modern human anatomy. See Jackschath, "Die Begründung der modernen Anatomie durch Leonardo da Vinci, etc." *Verhandlung der Gesellschaft deutscher Naturforscher und Aerzte, Karlsbach*, 1902. A. Forster in "Einiges über die Beziehungen Vesal's zu Leonardo da Vinci und zu Marc Antonio della Torre," *Archiv. f. Anatomie und Physiologie*, 1904, p. 197, discusses this paper and defends the reputation of Vesalius.

8, (p. 91). ANATOMY IN ENGLAND.

A special interest attaches to the development of schools of anatomy in England and Scotland because these schools have formed the chief model for courses in anatomy offered in this country. Dr. W. W. Keen in an address delivered before the Philadelphia School of Anatomy, a school closely modeled after the leading London school of a similar nature, gives the following account of the early development of practical anatomy in England. (A Sketch of the Early History of Practical Anatomy, Philadelphia, 1874, pp. 12-15.)

"England was among the first to profit by the shining example [of Italy]. Soon after the founding of the College of Surgeons in 1540, through the influence of Dr. Caius, the king's physician, and the founder of Caius College, Cambridge, Henry VIII granted to the College of Surgeons the privilege of dissecting four felons annually, and in 1564 Elizabeth gave the same privilege to the College of Physicians. In 1581 the latter college created the lectureship on anatomy, and in 1583 built in Knight Rider Street the first anatomical theatre. Here, in 1615, Harvey was elected lecturer, or, as it was then called, reader, in anatomy, and here he gave his first public demonstrations of the circulation of the blood about a year later.

"The facilities for general dissection, however, were very limited, and, as if to discourage it still further, in 1745 a fine of £10 was imposed on any one dissecting outside of the Barber-Surgeons' Hall. But such

a state of affairs could not long exist. The profession, under the lead of William Hunter, soon broke away from such bonds, and for over half a century almost every distinguished anatomist had dissecting rooms attached to his private dwelling, where he and his pupils cultivated the science. In 1770 William Hunter bought a lot in Great Windmill Street, London, opposite the Haymarket, and built on it a dwelling-house, an anatomical theatre, dissecting rooms, and a museum. The lecture-room was lighted from above, and the seats rose as in our own amphitheatres. Here he lectured, assisted by his brother John, by Hewson, and by Cruikshank, till his death, in 1783. Here he collected his splendid museum, now in Glasgow, at a cost of £100,000, and his brother John began his own collection, which cost him before its completion £70,000, and now forms the chief ornament of the Museum of the Royal College of Surgeons. At William Hunter's death the anatomical school passed into the hands of his nephew, Baillie, and then successively to Cruikshank, Wilson, Sir Benjamin Brodie, Sir Charles Bell, and Shaw, and finally to Mayo and Caesar Hawkins. On Mayo's removal, in 1833, to University College Hospital, this celebrated school came to an end. But it had left its mark. Thousands of educated anatomists had gone forth from its walls to practice all over Great Britain and in this country. It furnished William Hunter's museum to Glasgow in 1807, John Hunter's to the Royal College of Surgeons, London, and, later still, those of Wilson and Sir Charles Bell went to ornament the museum of the College of Surgeons of Edinburgh, and that of Mayo to University College, London. From it as a foster-mother, too, along with the institution of new public schools connected with the hospitals, many other private schools sprang up, and presented the finest opportunity for the diffusion of anatomical knowledge, so that in 1825-6, besides the hospitals, there were no less than seven such private schools of anatomy in London. . . .

"I have already quoted the Edinburgh act of 1505, which allowed of the annual dissection of a criminal, and also the early experience of the first Monro, which shows how rarely this was made available. The first Scotch anatomical theatre was built, and the first public demonstrations given, in 1697. But it was not till 1720 that a regular professor was appointed. At that date Monro primus was elected professor, at the extraordinary salary of £15 per annum! From this time till 1859, when Monro the third died, the history of Edinburgh anatomy and that of this astonishing family, are almost identical. True, John Bell and Knox, Charles Bell, Barclay, Innes, and others, lectured in private schools; but the Monros held the sceptre. All of them lived to old age, Alexander primus dying at seventy, Alexander

secundus at eighty-four, and Alexander tertius at eighty-six. All were professors early in life; at twenty-three, twenty-one, and twenty-five respectively. All of them taught for long periods: thirty-eight, fifty-four, and forty-eight years; and father, son, and grandson, they held the anatomical chair in Edinburgh from 1720 till 1846, a period of one hundred and twenty-six years!"

9, (p. 91). ENTRANCE OF ANATOMY INTO RUSSIA.

Into the western countries of Europe anatomy was extended as a natural result of awakened popular intellectual interests. Into Russia it was forced by the arbitrary will of Peter the Great. Sunk in superstitious barbarism, the Russian people are said during the seventeenth century to have had the greatest horror of dissection. The Dutch physician Bremburg went to Russia in 1626 and carried with him a skeleton for study. When this was learned he was almost lynched by the people and had to leave the country. (von Töpley, Neuburger and Pagel, *Handbuch der Geschichte der Medicine*, 1902, Vol. 2, p. 317.) In 1697 Peter made his memorable journey to Holland. Here he studied the microscope under the great naturalist Leeuwenhoek, and human anatomy under Ruysch, whose beautiful cabinet of anatomical preparations he afterward bought. The collection is in part still to be seen in the Academy of Science at St. Petersburg. Many of the specimens are said to have been ruined in their trip from Holland to Russia because the Russians who had them in charge drank up the alcohol in which they were preserved. Peter founded a military hospital at Moscow and a medico-surgical school at St. Petersburg, and, acting under the advice of the great German philosopher, Leibnitz, left the plans for the establishment of the Academy of Science where anatomy has since been cultivated by some of the greatest of its students.

10, (p. 91). ANATOMY IN GERMANY.

The following table shows the number of professors, instructors and servants, and the amount of yearly appropriation for the anatomical and physiological institutes, the number of students in anatomical courses, and the yearly appropriation for laboratories and museums of other departments in the German universities during the year 1892-3. Since that date there has been a general increase, but not of the remarkable nature which is to be seen today in the American universities. From 1891 to 1899, for instance, the number of "ordentliche"

DEPARTMENTS IN GERMAN UNIVERSITIES, 1892-3.

UNIVERSITIES.	ANATOMICAL INSTITUTES.										PHYSIOLOGICAL INSTITUTES						APPROPRIATIONS FOR OTHER INSTITUTES.					
	Professors.	Assistant Professors.	Docents.	Prosectors.	Assistants.	Servants.	Number of students.	Appropriations (Marks).	Professors.						Pathology.	Pharmacology and physiol. chem.	Hygiene.	Zoology (including museums).	Botany (including garden).	Physics.	Chemistry.	
									Professors.	Assistant Professors.	Docents.	Instructors.	Servants.	Appropriations (Marks).								
Berlin.....	I	I	I	I	I	I	500	40,540	I	3	...	7	I	16,396	21,450	17,202	21,280	87,110	105,625	28,650	21,000	
Bonn.....	II	I	...	...	...	...	125	11,430	I	I	...	3	I	12,635	10,160	6,250	18,630	20,560	31,550	3,000	17,135	
Breslau.....	I	I	...	...	...	...	170	16,358	I	I	I	I	I	11,039	13,312	5,800	1,500	18,206	22,536	7,575	25,710	
Braun.....	I	I	...	...	...	...	95	6,831	I	...	...	I	I	8,410	6,510	...	...	9,156	29,994	7,552	13,561	
Freiburg.....	I	I	I	I	I	I	135	6,000	I	...	...	I	I	2,000	3,600	510	1,500	2,500	3,971	2,900	9,600	
Gießen.....	I	...	I	I	...	I	45	6,857	I	...	...	I	I	4,080	7,870	2,430	4,570	6,500	1,880	1,220	13,000	
Göttingen.....	I	I	...	...	...	...	105	11,180	I	I	...	I	I	6,855	8,080	5,100	5,100	9,500	21,890	9,010	30,810	
Greifswald.....	I	I	I	I	I	I	160	13,571	I	...	...	I	I	6,170	6,800	3,950	...	6,432	12,411	7,310	12,603	
Halle.....	I	I	I	I	I	I	100	15,319	I	...	...	I	I	5,414	7,924	3,110	4,110	9,149	18,603	8,835	14,033	
Heidelberg.....	I	I	I	I	I	I	...	6,790	I	...	...	I	I	6,000	3,000	2,200	1,500	5,000	11,000	2,200	11,000	
Jena.....	I	I	...	...	...	...	95	11,400	I	I	I	I	I	1,900	3,600	...	2,000	3,500	8,000	4,500	...	
Kiel.....	I	I	...	...	...	...	80	10,100	I	...	...	I	I	6,850	7,500	3,200	4,550	7,400	13,650	5,980	11,600	
Königsberg.....	I	I	I	I	I	I	100	16,172	I	I	...	I	I	5,780	8,120	3,910	4,150	10,018	15,030	10,550	11,350	
Leipzig.....	I	I	I	I	I	I	325	16,290	I	...	...	I	I	10,030	7,230	6,710	5,000	5,593	20,713	6,000	26,650	
Marburg.....	I	I	I	I	I	I	155	13,356	I	...	...	I	I	12,989	9,632	4,982	4,212	6,600	17,808	8,450	15,209	
Munich.....	I	I	...	...	...	...	200	21,529	I	...	...	I	I	6,969	15,681	5,325	37,084	...	13,350	8,965	17,987	
Rostock.....	II	I	...	...	...	...	...	3,900	I	...	...	I	I	3,450	5,850	4,100	2,350	6,100	7,245	3,950	7,400	
Strassburg.....	I	I	I	I	I	I	40	17,788	I	I	...	I	I	7,575	12,088	9,125	...	5,975	14,775	13,080	26,250	
Tübingen.....	I	I	I	I	I	I	100	19,772	I	I	...	I	I	4,555	9,333	6,369	...	8,230	19,010	...	11,710	
Würzburg.....	I	I	I	I	I	I	300	21,190	I	...	...	I	I	10,882	11,386	3,300	3,210	8,147	13,183	8,221	21,007	
Würzburg.....	II	...	...	...	...	...	...	3,834	...	...	...	...	...	...	...	...	...	...	...	...	...	

professors in the medical faculties increased from 211 to 224, and the number of students from 27,057 to 32,834. At Breslau, the yearly appropriation for the anatomical laboratory for 1893 was 16,358 M. In 1903 it was 25,478 M. But such an increase is unusual.

This table is based primarily on data given in W. Lexis, "Die deutsche Universitäten," 1893. See also Minerva and W. Lexis, "Die deutsche Universitäten," 1904.

11, (p. 91). ANATOMICAL PERIODICALS.

Waldeyer in Merkel-Bonnet's *Ergebnisse* for 1902 reviews 178 periodicals devoted in part or wholly to anatomy.

12, (p. 92). PHYSIOLOGY.

H. Boruttau in Neuburger and Pagel's *Geschichte der Medicin*, Bd., II., p. 455, gives the following dates of the establishment of separate physiological institutes in the German universities:

Breslau	1811	Marburg	1848
Königsberg	1849	Tübingen	1853
Kiel	1855	Heidelberg	1857
Berlin	1858	Bonn	1859
Jena	1860	Göttingen	1861
München	1863	Leipzig	1865
Rostock	1865	Würzburg	1865
Freiburg	1867	Halle	1870
Erlangen	1872	Greifswald	1872
Strassburg	1872	Giessen	1891

13, (p. 96). ANATOMY AND PHYSIOLOGY.

Thus Hertwig ("Die anatomische Unterricht," Jena, 1881, p. 23) says:

"With all this one should not lose sight of the fact that since physiology has become independent the real purpose and the immensely wide and still rich field of work for anatomists is morphology. In this lies the center of gravity of their activity, which while extended out to be sure to wider fields at the same time must not be quite misplaced at the cost of morphology in the direction of physiology."

Yet both in this article and elsewhere Hertwig recognized that "every division of a science into special fields, as for instance of

biology into anatomy and physiology, is an artificial one and one not to be strictly carried through. Structure and function of a part hang together in innermost union and can in truth be understood only while united.

"As unfounded as vitalism is the mechanical dogma, that life with all its complicated phenomena is nothing else than a chemico-physical problem." (Hertwig. "Biologie im 19 Jahrhundert," Jena, 1900.)

If teleological anatomy were to be avoided by physiologists because physics and chemistry are limited in their application to it, and by anatomists because it is not a pure study of structure, a fertile field of study would be neglected. As a matter of fact the highly developed and important subject of the movements effected by the voluntary musculature, and that of Mayo to University College, London. From it as a whole is neglected in most of the text-books on physiology used by American students and is most inadequately treated in the modern popular text-books of anatomy.

14, (p. 97). MEDICAL SCHOOLS IN AMERICA PREVIOUS TO THE PRESENT REFORM.

A private course in human anatomy was offered at New York by Doctors John Bard and Peter Middleton as early as 1750, and one by Thomas Cadwallader at Philadelphia at about the same time. In 1752-55 a series of public lectures on human and comparative anatomy and the history of anatomy was given at Newport, R. I., by Dr. William Hunter, a relative of the famous English anatomists, John and William Hunter. In 1762 Dr. W. Shippen advertised in the *Pennsylvania Gazette* as follows: "Dr. Shippen's anatomical lectures will begin to-morrow evening at six o'clock at his father's house in Fourth St. Tickets for the course are to be had of the Doctor at 5 pistoles each, and any gentlemen who incline to see the subject prepared for the lectures and learn the art of dissecting, injection, etc., are to pay 5 pistoles more." In 1765 Dr. Shippen and Dr. John Morgan, both of whom had been favorite pupils of the Hunters in London and had later graduated at Edinburgh, organized a school of medicine as a department of the Pennsylvania College, afterwards the University of Pennsylvania. Similar institutions were organized by active young physicians and established in connection with various literary colleges, among them one at Kings, afterwards Columbia College, New York, in 1768; Harvard College, Cambridge, 1783; Dartmouth College, New Hampshire, 1797; University of Maryland, Baltimore, 1807; Yale College, New Haven, 1810; Brown University, Providence, R. I., 1811; Transylvania Univer-

sity, Lexington, Ky., 1817; Bowdoin College, Portland, Me., 1820, and the University of Virginia in 1822.

In 1807 the Regents of the University of New York fathered the establishment of a College of Physicians and Surgeons at New York City, and in 1813 of one at Fairfield, N. Y. In 1823, under the charter of Williams College, the Berkshire Medical Institute was established at Pittsfield, Mass. In 1813 the medical department of Columbia University was discontinued and the faculty passed over to the College of Physicians and Surgeons.

In the *Harvard catalogue of 1846-7* an interesting account is given of the foundation of the Harvard school. It is quoted here in part as an example of the method of establishment of these early schools: "Before the Revolution no medical school existed in Boston, nor in the State of Massachusetts. No examinations and no licenses to practice were established, nor any other means by which the public could be assured of the qualifications of a medical practitioner. There were no dissections, and even examinations of the bodies of deceased persons were rarely permitted. The means of instruction were limited to the information that could be obtained from the private practice of the physician, and to reading the very few books which he might have in his library. Now and then a favored individual went home to England, as it was said, to walk the hospitals of London, and to attend lectures at the great institution at Edinboro'. Some time before the Revolution, in 1765, a medical school was established in Philadelphia, and afterwards, in 1768, one in New York; but the modes of traveling were so imperfect that these cities were considered almost inaccessible from this part of the country.

"The Revolutionary War supplied abundant opportunities of cultivating practical medicine and surgery, and the murmurs of prejudice against anatomy were not heeded amidst the bustle of the camp and the cries of the wounded. Under such circumstances were found many good physicians and surgeons, among whom was Dr. John Warren, of Boston.

"This gentleman was a surgeon in the army from the battle of Bunker Hill to the end of the campaign in the Jerseys. Being then compelled by illness to quit the army, he settled in Boston, was there appointed Military Hospital Surgeon, and improved the opportunity this situation afforded for cultivating the study of anatomy to an extent till then unknown in this place. In 1781 he began a course of lectures on Anatomy, which was attended by physicians in practice, and by a few medical students. These lectures attracted so much attention, that the

Government of Harvard University invited Dr. Warren to lecture at Cambridge, and give his aid in the formation of a medical school.

"This school was established, and went into operation in 1783. Dr. Warren was Professor of Anatomy and Surgery, Dr. Aaron Dexter of Chemistry and Materia Medica, and Dr. Benjamin Waterhouse of the Theory and Practice of Medicine. The lectures of these gentlemen were attended by medical students from different parts of New England, usually in number about twenty, and also by those members of the Senior Class of the University who obtained the consent of their parents. The opportunities for dissection were generally limited to one subject in the course, and the efforts required to carry this subject through the course, at the time when Boston did not communicate with Cambridge by any bridge, were very great. The lectures were generally from two to three hours long but were attended steadily, and listened to closely. The degree of Bachelor of Medicine was first conferred in 1785, and, according to the system then followed, after the lapse of seven years that of Doctor of Medicine.

"Medical instruction continued in this condition until the year 1809. At this time a public dissecting room was opened at No. 49 Marlboro' street by Dr. John C. Warren, son of the Professor of Anatomy, who had been appointed Adjunct Professor three years before, viz.: in 1806. The demonstrations and dissections given at that period were attended by most of the younger physicians of the town, and by some medical students. In 1809 Dr. John Gorham was chosen Adjunct Professor of Chemistry.

"As Cambridge did not afford any opportunities for seeing medical and surgical practice, the number of students there did not materially increase, and it was proposed, and finally arranged, that the medical institution should be transferred to Boston. This arrangement was effected on the condition that certain Professors should give lectures to one or more classes at Cambridge. A course on Human and Comparative Anatomy has accordingly been given annually in the spring by the Professor of Anatomy, and a course of Hygiene by the Professor of Medicine."

The *early schools* were established primarily on the plan of the English and Scotch medical schools and were designed to offer short terms of didactic lectures, practical anatomy and clinical instruction to students whose main education was gained through apprenticeship in a physician's office. The Hunters had offered facilities for dissection to their students and this example was followed in the first schools in this country and in all those subsequently established. In this respect the

American schools were for some time in advance of many of the continental institutions.

Thus His in his address at Basel in 1885 (*Gedenkschrift zur Eröffnung des Vesalianum*) showed that in the university in that city, where once the great Vesalius taught, practical human anatomy really began with the professorship of Jung in 1823.

Welch has pointed out (*Biology and Medicine*, University Record, Chicago, July, 1897, Vol. II, p. 142) that human anatomy was the only subject anywhere taught by the laboratory method until the end of the first quarter of the present century. In 1824 Purkinje established a physiological laboratory in Breslau and in 1825 Liebig one in chemistry at Giessen. The Hunters seem to have been the first to offer students free facilities for dissection. As a rule previously anatomy had been taught by demonstration.

Early in the nineteenth century the medical schools in America began to multiply rapidly in number. From 1776 to 1810 there were seven schools started; from 1810 to 1840, twenty-six; from 1840 to 1875, forty-seven. Of these eighty schools sixteen had been discontinued by 1876.

The best accounts of the medical schools up to 1876 are those by N. S. Davis, entitled, "Contributions to the History of Medical Education and Medical Institutions in the United States of America, 1776-1876." (Special Reprint U. S. Bureau of Education, 1877), and by J. M. Toner, "Contributions to the Annals of Medical Progress in the United States before and during the War of Independence." (U. S. Bureau of Education, 1874.)

Standards of medical education fell as schools multiplied. Schools connected with the literary institutions dissolved their connection either wholly or in part, and that decline set in which for the better part of a century was so often deplored by the idealists in the medical profession.

In most schools only two decades ago the entrance requirements were merely nominal and a diploma was granted to anyone who would pass a nominal year of apprenticeship with a physician and listen three months for two successive years to a hodge-podge of lectures on the medical sciences and medical practice.

Some other facilities than those of the short lecture term were, however, offered in the better schools, especially in the large cities. The student could attend clinics, practice dissecting, and often had the privilege of listening to a second set of lectures if he wished. For these various privileges extra fees were usually, though not always, charged. The fees for the regular lecture courses varied from \$75.00

to \$140.00 in the leading schools. Previous to the establishment of laboratories the expenses, except for cadavers, were small, and large incomes were derived by the proprietor-professors of many of these schools.

The medical schools of the country were thus described by the Commissioner of Education in 1870:

"The medical colleges of the country are mostly joint stock corporations which furnish as little medical education as they can sell at the highest rate they can obtain. Their number is excessive and the competition between them very keen. They are consequently disinclined to introduce any new features which may scare away students of low acquirements or which may add seriously to the expenses of the institution." (U. S. Bur. Ed. Rep., 1870, p. 395.)

In 1892 a committee of French specialists made a study of medical education in the United States. From their report (U. S. Bureau of Education, Report, 1892-3, pp. 601-613) the following remarks may be quoted:

"Young physicians who wish the title of professor route out the statutes (for a medical school), elect a council of administration, and request the state authorities to inscribe the new creation in official registers. This is seldom refused and is equal to a regular authorization. The prospectuses are freely issued in order to announce the new creation; the medical papers publish the courses and the list of the professors who but yesterday were but simple physicians, more or less unknown. This is business; it must be hurried, and here, as everybody knows, the Americans are at home. Students come in greater or less numbers and in the second year diplomas are distributed. The graduates are then permitted to practice medicine in the State where the school is established."

"At first the resources of the school are limited, as the fees of the students and the sum given by the founders are the only sources of revenue. The buildings are rudimentary, and the laboratories poorly and meagrely equipped. But if by chance some distinguished and energetic person has come into the corporation, reputation does not wait for the lapse of years and endowments increase. Splendid iron and brick buildings are erected, dispensaries and soon hospitals are founded."

"The medical career is a profession like any other and the epithet 'liberal' would not be understood in a country where only one thing is desired, namely, to gain with the greatest rapidity the greatest possible amount of money; where the effort is only to perfect oneself in his art

in order to get still richer. Therefore, of course, no one thinks of erecting high barriers at the entrance to the schools.

"The professional courses which the student must follow bear a close analogy to those which the professors of our provincial schools have to give. The lectures even at Philadelphia and New York hardly bear comparison with those in the faculties of Bordeaux and Nancy. In America there is nothing to be compared with the faculties of Lyons and especially those of Paris. The theoretical courses are generally good but elementary; the exercises in dissection are as a rule rudimentary. The practical work, except in chemistry, leaves much to be desired. On the contrary this is not the same with dental schools, the triumph of the United States."

In some instances "sun down" and "night" schools have been and still are maintained in order to make doctors out of working men by giving them didactic lectures evenings after the day's work is finished. (See Dexter, "History of Education in the United States," 1903. Reference is here made to some of the literature bearing upon the subject of medical education in the United States.)

Of the nominal three years of medical study which were required the following description gives a good picture of the first:

"The student remains in the medical man's office for a period varying from three months to a year, during which, if his preceptor is a busy man and popular practitioner, he has not been examined on the progress he is making enough to make it worth mentioning or remembering. He during this time reads some work on human anatomy without any appliances except a defective set of bones, the relics of his preceptor's dissecting days, and perhaps a fair set of anatomical plates; he also reads some books on physiology, materia medica, and perhaps chemistry, and even attacks the theory and practice of medicine; sometimes, moreover, surgery is also read. During all this route he is apt to be bothered by the strange and seemingly barbarous phraseology of these works and to wonder why the language he is accustomed to speak cannot describe the facts his eyes see," etc. (U. S. Bur. Ed. Rep., 1870, p. 395.)

After some such course of learning the student for two successive years attended lectures at a medical school.

The following account of the *mode of teaching* by one of the brightest teachers at one of the best of the schools previous to the present reform indicates well that what the conditions in medical schools in this country were until a comparatively short time ago.

"Dr. Cheever writes:

'It nears one o'clock, and the close work in the demonstrator's room in the old Medical School in North Grove Street becomes even more hurried and eager as the lecture hour in Anatomy approaches. Four hours of busy dissection have unveiled a portion of the human frame, insensate and stark, on the demonstrating-table. Muscles, nerves, and blood-vessels unfold themselves in unvarying harmony, if seeming disorder, and the "subject" is nearly ready to illustrate the lecture. . . The room is thick with tobacco smoke. The winter light, snowy and dull, enters through one tall window, bare of curtain, and falls upon a lead floor. The surroundings are singularly barren of ornament or beauty, and there is naught to inspire the intellect or the imagination, except the marvellous mechanism of the poor dead body, which lies dissected before us, like some complex and delicate machinery whose uses we seek to know.

'To such a scene enters the poet, the writer, the wit, Oliver Wendell Holmes. Few readers of his prose or poetry could dream of him as here, in this charnel-house, in the presence of death. The very long, steep, and single flight of stairs leading up from the street below resounds with a double and labored tread, the door opens, and a small, gentle, smiling man appears, supported by the janitor, who often has been called on to help him up the stairs. Entering, and giving a breathless greeting, he sinks upon a stool and strives to recover his asthmatic breath. . .

'Anon recovering, he brightens up, and asks, "What have you for me to-day?" and plunges, knife in hand, into the "depths of his subject,"—a joke he might have uttered. Time flies, and a boisterous crowd of turbulent Bob Sawyers pours through the hall to his lecture-room, and begins a rhythmical stamping, one, two, three, and a shout, and pounding on his lecture-room doors. A rush takes place; some collapse, some are thrown headlong, and three hundred raw students precipitate themselves into a bare and comfortless amphitheatre. Meanwhile the professor has been running about, now as nimble as a cat, selecting plates, rummaging the dusty museum for specimens, arranging microscopes, and displaying bones. The subject is carried in on a board; no automatic appliances, no wheels with pneumatic tires, no elevators, no dumb-waiters in those days. The *cadaver* is decorously disposed on a revolving table in the small arena, and is always covered, at first, from curious eyes, by a clean white sheet. Respect for poor humanity and admiration for God's divinest work is the first lesson and the uppermost in the poet-lecturer's mind. He enters, and is greeted with a mighty shout and stamp of applause. Then silence, and there begins

a charming hour of description, analysis, simile, anecdote, harmless pun, which clothes the dry bones with poetic imagery, enlivens a hard and fatiguing day with humor, and brightens to the tired listener the details of a difficult though interesting study. We say tired listeners because—will it be believed?—the student is now listening to his *fifth* consecutive lecture that day, beginning at nine o'clock and ending at two; no pause, no rest, no recovery for the dazed senses, which have tried to absorb *Materia Medica*, Chemistry, Practice, Obstetrics, and Anatomy, all in one morning, by five learned professors. One o'clock was assigned to Dr. Holmes because he alone could hold his exhausted audience's attention.'” (Morse, J. T., *Life and Letters of Oliver Wendell Holmes*, vol. I, pp. 174–176.)

Of course few students were privileged to listen to so entertaining a talker as O. W. Holmes but the description here given offers a fair picture of one of the three chief parts of the old fashioned course in anatomy, the didactic lecture illustrated by demonstrations on a dissected body. Practical dissection formed another part of the course. The bodies were often limited in number and poorly preserved. The dissecting rooms were usually large rooms in the attic of the medical building. Dissecting was done mainly at night in the midst of a noisy disorderly crowd of smoking and expectorating youths mentally weary from the day's lectures and full of animal spirits seeking outlet. The general conditions of disorder may be best realized from the fact that it was considered a great luxury and the mark of an advanced and up-to-date school if the dissecting room was furnished with a cement floor that might from time to time be flushed with a hose.

It is needless to say that there was little opportunity for that quiet so necessary for scientific insight. In large part the teaching of anatomy was left to practicing surgeons who came to look upon it as an appendage to their trade. The professor of anatomy, usually a man engrossed in the practice of medicine, gave didactic lectures on the subject while the demonstrators of anatomy, who overlooked the work in the dissecting room, were young men waiting for patients and looking forward to being surgeons. To most of them it seemed that enough anatomy for practical surgery was to be found in the text-books and that the ideal was to learn them by heart. Few seemed to realize that a surgeon usually has text-books at hand, so that memorizing more than a few essentials is as unnecessary as learning the directory of a city by heart when one moves to a new town. But teachers who have no burning interest to deepen their own understanding of the subject they profess always tend to encourage routine memorizing of authoritative data. And thus medical students were led to devote the major

part of their time to text-books in preparation for quizzes rather than to training their powers of observation and manual dexterity in the dissecting room. From quiz-masters one can expect few real contributions to science and few were made.

The third part of the work in anatomy consisted of the quizzes in preparation for the examinations in anatomy. This portion of the work assumed an increasing importance soon after several of the States instituted examinations for licenses to practice. The examinations within the school then naturally were made more severe because no school liked the reputation of having many of its graduates fail to pass the State examinations. Frequently the quizzes formed a part of the instruction offered by the school but in a great many instances private quizzes were given by some of the teachers in the school, by some of the older students or by persons not officially connected with the school. Often considerable incomes were derived by the quiz-masters.

While I have described the above methods of teaching anatomy in the past tense it is not to be assumed that they have been entirely superseded by more rational methods. In a comparatively few schools have the recent waves of reform managed to sweep entirely away the rubbish of the past.

15, (p. 97). SUPPLY AND CARE OF ANATOMICAL MATERIAL.

For the early schools in this country bodies were obtained only with difficulty and, as in England, professional body-snatchers had to be employed previous to the enactment of State laws which give to the medical colleges the bodies of those dying without friends. The house of Dr. Shippen of Philadelphia was attacked in 1765 by a mob the members of which were excited by the report that the church burying-ground had been despoiled to furnish material for his private class in anatomy, an accusation which he denied. (W. W. Keen, *Sketch of the Early History of Anatomy*, p. 15.) In New York soon after the close of the war of the Rebellion a mob excited by the report of stolen bodies broke into the dissecting room at Columbia College and precipitated a riot which lasted for two or three days. Often great difficulties were encountered. Early in the thirties Dr. Beck is said to have carried bodies in a buggy all the way from Boston to Albany in order to supply material to his classes in the latter city. Even up to very recent years scandals connected with the supply of anatomical material have occurred from time to time.

In 1830 Massachusetts passed a law giving the bodies of paupers dying in State charge and in 1833 one giving those of county paupers unclaimed by friends to the recognized medical institutions of the State. "But these acts," says W. W. Keen (*Early History of Anatomy*), "were only obtained after the community had been driven to it, not only by the repeated outrages to the public peace and public feelings, but also by repeated crimes." Other States passed similar laws. The Pennsylvania law, passed in 1868, although at first rendered difficult of operation by popular prejudice, paved the way for the law of 1883 which has served as a model for many similar laws. Dr. Keen in a recent letter to the writer says concerning the law: "May I call your attention to one point in particular? The anatomy law of Pennsylvania, so far as I know, is the best law of its kind in this country. *It gives us more material for dissection than we know what to do with.* Not only are medical schools, but individuals, county societies and colleges which have a biological course, supplied with bodies freely. All of the details can be given you, if you desire them, by Dr. Addinell Hewson, 1115 Spruce St., Philadelphia, the Secretary of the Board. It is a very curious fact that the gentleman who drew up the law, my colleague, Professor William S. Forbes, of the Jefferson (Medical School), was its first and only victim! By the very timely death of his father-in-law, the hearing of his case was postponed, interest in it finally died out, and in some way (I do not remember just how) he escaped any trouble."

In the Proceedings of the Association of American Anatomists, 1896 (*Science*, III, 1896), may be found the report of a special committee of the Association which investigated the laws relative to anatomical material in this and several foreign countries. In this report an abstract of the Pennsylvania law is given and the law is highly commended. In essence the law reads that all unclaimed bodies of persons dying in public charge shall be turned over to an anatomical board for distribution for scientific purposes. Today in many States ample legal provision is made for legitimate needs. Still we find the professor of anatomy at the University of Texas complaining as late as 1902 that he has to purchase bodies obtained in an irregular manner because the State laws are inadequate to furnish the State University with material. (See President's Report, University of Texas, 1902.)

The professor of anatomy of another medical school connected with a State University has recently informed the writer that those in charge of the state and county public institutions, which furnish unclaimed bodies for scientific study, demand from ten to twenty dollars for each body and even then the supply is so limited that he is forced to turn

to irregular channels for an adequate supply of material. Although state laws strictly forbid traffic in bodies there is a firm in one of the Southern states that furnishes bodies to institutions situated in several of the Northern states, and other firms supply more limited territories.

In a recent article (*Anatomical Material, Its Collection and Its Preservation at the Johns Hopkins Anatomical Laboratory*, the *Johns Hopkins Bulletin*, vol. 16, 1905) Professor F. P. Mall gives an interesting account of his experiences when the Johns Hopkins Medical School was established in 1893. At that time but forty-nine bodies came through regular channels to supply the twelve hundred students in the various medical schools of Baltimore and the new school but increased the demand on the inadequate supply. For a time recourse had to be made to irregular sources of supply. The organization of a strong Anatomical Board, composed of members elected from the faculties of the several schools and the enlistment of the services of the Commissioner of Health of Baltimore has since served to offset the inadequacies of the present State laws in Maryland and to furnish all schools with a fairly adequate supply of material.

In the report of the Committee of the Association of American Anatomists, referred to above, an account is also given of the methods utilized for preserving bodies in this country. The limited supply furnished, until comparatively recently, necessitated that the bodies be embalmed instead of being dissected fresh. This latter method is still the practice in many parts of Europe.

Of recent years material is more plentiful but it is still felt in the leading schools that it is better for a student to dissect a small amount of material carefully and thoroughly rather than a large amount of material rapidly and superficially. Methods of preservation are therefore of importance. Many methods have been used. For a description of these see the Report of the Committee mentioned above. The best preserved bodies for purposes of dissection which I have seen in the dissecting rooms of this country are those injected with a mixture of alcohol, carbolic acid and glycerine. Where a large number of bodies are preserved cold-storage is of great advantage.

The use of cold-storage for the preservation of bodies intended for dissection was introduced by Professor Huntington at Columbia University in 1893 and soon afterwards at the Johns Hopkins University by Professor Mall. In the recent paper referred to above Professor Mall comes to the conclusion that while cold-storage is of advantage in many ways it is by no means essential. He recommends vats in which bodies may be immersed in 3% carbolic acid. In several institu-

tions the cold-storage plants have been discontinued and the bodies injected with the carbolic acid mixture and wrapped are found to keep well in an alcohol saturated atmosphere.

In addition to the report of the Committee of the Association of American Anatomists, see F. P. Mall, "Anatomical Courses at the Johns Hopkins University," *Bulletin of the Johns Hopkins Hospital*, May-June, 1896; and "Preservation of Anatomical Material," *idem*, Feb., 1905; A. T. Kerr, the *Johns Hopkins Bulletin*, VII, 1901.

16, (p. 97). ANATOMY IN THE BETTER OF THE OLDER SCHOOLS.

At the time of the foundation of the earliest medical schools in this country the foremost institutions for the practical study of human anatomy were the Windmill Street School of the Hunters in London and the Edinburgh School under the Monros (see note 8). The best of the early teachers of human anatomy in this country were trained in these schools and brought with them to this country high ideals of the value of practical dissection and of comparative vertebrate anatomy.

At the *Medical Department of the University of Pennsylvania* Dr. John Morgan, one of the founders, was a pupil of the Hunters. His publication on "The Art of Making Anatomical Preparations" led to his election to membership in the Royal Society of London. Dr. William Shippen, a friend and fellow-student of Morgan's, was professor of anatomy, surgery and midwifery at the medical school for forty-three years.

From 1808 to 1818 Casper Wistar was professor of anatomy. Thomas Jefferson wrote to Wistar in 1807, "I have a grandson, the son of Mr. Randolph, now about fifteen years of age in whose education I take a lively interest . . . there are particular branches of science which are not so advantageously taught anywhere else in the United States, as in Philadelphia in your Medical School for anatomy, etc." (See Benjamin Franklin and the University of Pennsylvania, F. H. Thorpe, U. S. Bur. of Ed., Circul. of Information, 1892. No. 2.)

From 1819 to 1831 Dr. Philip S. Physick was professor of anatomy, from 1831 to 1853 W. Horner, and from 1853 to 1891, J. Leidy.

Wistar wrote a good text-book on human anatomy and made a contribution to the structure of the ethmoid bone; W. E. Horner wrote a text-book on "Special Anatomy and Histology," and a "United States Dissector," discovered the tensor tarsi muscle (*London Med. Repository*, 1822), and among other papers contributed one on the "Odorifer-

ous Glands of the Negro." (Am. Jourl. of Med. Sc., Vol. XXI, p. 13.) Wistar founded and Horner did much to develop the fine collection of anatomical specimens now beautifully housed in the Wistar Museum, erected in 1892 through the generosity of General Wistar. J. Leidy, one of the best known of American scientific investigators, a man whose interests ranged over wide fields, contributed chiefly to the subjects of helminthology and vertebrate paleontology. He was a beloved teacher of human anatomy and wrote a text-book on the subject. (See T. G. Lee, Proceedings American Academy of Science, XXVII, pp. 437-442.) Since the death of Leidy, G. A. Piersol has been professor of anatomy.

The stimulus given to medical education by Morgan, Shippen and other Philadelphians who had received inspiration from the teachings of the Hunters made Philadelphia the foremost center of medical education in this country for nearly a century. Following the English example numerous private schools for teaching anatomy and other subjects were established by the leading physicians of the city and in 1825 the *Jefferson Medical College* was established and long rivalled the Medical School of the University in popularity. In 1832 G. S. Patison, "formerly professor of anatomy in the University of Maryland and lately professor of anatomy and surgery in the University of London," was made professor of anatomy. The following quotation from the catalogue of the University for 1832 will show the ideals held by one of the leading teachers of the day.

"The value of the extensive Museum as an appendage to a school of Medicine, is too self-evident to require argument. To the Professor, as a source for obtaining objects for the illustration of his lectures, it is invaluable, and to the Student it is no less so. It is to him a field to which he can constantly refer for a solution of his doubts and difficulties. Visiting the Museum, and assisted by the explanations of his Professor, subjects which may have appeared to him during the lectures full of difficulty, are rendered simple and intelligible. In the present advanced state of Anatomical Science, how is it possible for the Professor to teach, or the Student to understand its minutiae, without the aid of preparations? How can the Professor of *Materia Medica* instruct his pupils, without exhibiting to them, in all their states, the difficulties of the *Materia Medica*? The eye is a most important organ in the acquisition of knowledge, and whenever the teacher can bring it into operation, he should not fail to do so. Having at his command an extensive collection of Preparations, his lessons can be forcibly fixed on the memories of his pupils by ocular demonstration.

"Abroad, a Museum is considered as absolutely essential to every system of Medical tuition; and the magnificent collections of the Hunt-

ers, and the Monros, &c., in Great Britain, and of Sömmerring, Meckel, Rudolphi, and Cuvier, &c. on the Continent of Europe, prove the value which these Masters attached to preparations as instruments of instruction in Medical Science. Unfortunately, in our own country, sufficient attention has not heretofore been given to forming extensive collections of preparations. The arrangements of our Medical Institutions are, in many respects excellent, and the distinguished men which they have educated have conferred the highest honor on their Professors. But, although we feel proud in the admission of this fact, we are constrained to acknowledge that no school in our country has as yet collected such a Museum as to be sufficient for the illustration of the lectures of the Professors. Indeed, our best collections are inferior to those possessed by the most paltry private School in Europe. It is the determination of the Professors of Jefferson Medical College, that this *desideratum* shall no longer be allowed to exist in their Institution. Rich as the United States is in all the subjects of the Vegetable, Mineral, and Animal Kingdoms, and liberally supplied as Philadelphia, in particular, is, with Dead Bodies, there is no reason why they may not in a very few years, have open for the examination and instruction of their pupils, a splendid and extensive collection of the various subjects of their lectures.

"The present Museum belonging to Jefferson Medical College, as compared with the other collections attached to similar institutions in this country, is a respectable one. It will serve as a nucleus for the formation of a magnificent Museum, and the Professors trust they will have the co-operation of the Profession, and of their Students, in the accomplishment of this desirable object.

"It is customary in many of the Medical Institutions of Europe, for the Students attached to them to prepare, during the course of their studies, an Anatomical Preparation, and to leave it in the College Museum, as a memorial of their connection with their Alma Mater, The Professors hope that this example will be followed by the young gentlemen who may in the future be educated in Jefferson Medical College. The name and date being inscribed on the specimen, it serves to perpetuate the connection which has existed between the Students and their Professors, and in years afterwards, when they shall have become distinguished members of the Profession, should they, or their children, visit the Halls of their former studies, the preparations they have made will recall to the former delightful recollections, and will afford to the latter a powerful incentive to exertion. The Son would feel unworthy not to emulate, and, if possible, excell the Father in his devotion to his studies.

"Another and an important advantage, will be gained by the Student leaving as a gift a Preparation to the Institution where he has been educated. To make a handsome Anatomical Preparation, very considerable labour is required, and it is a kind of labour the most valuable to the surgeon. It gives him dexterity in the use of the scalpel, a dexterity without which no man can ever become able and distinguished as an operator.

"*Practical Anatomy* is, of all the departments of his studies, the one from which the Student of Medicine will derive most benefit during the term of his Collegiate Studies. Every other branch may be studied, and studied with advantage, after he has graduated. Indeed, all the Professors can hope or expect to accomplish by their Lectures is, by laying before the pupils, with clearness and perspicuity, the leading principles of the science they teach, to prepare their minds for the reception and investigation of medical truths. The Professor merely lays the foundation on which the Student is afterwards, by his own diligence, observation, and study, to raise himself to eminence and usefulness in his profession. With the exception of Anatomy, therefore, all a Student can expect to acquire during the term of his attendance on Lectures, is merely the great outlines of Medical Science. But this season, unfortunately, by the regulations of the Medical Schools of our country, a very limited one, is the only period that he will ever have for the acquisition of anatomical knowledge. Anatomy, the basis of all medical reasoning, can only be studied *practically*, during the term of the Student's attendance on Lectures. Should he neglect his opportunities for acquiring a competent knowledge of the science during the term passed by him at College, he must be content to continue forever afterwards a mere driveller in his profession. Now, Anatomy is not to be learnt by an attendance on Lectures. Dissection, and dissection alone, can make a man an Anatomist. The Professor of Anatomy, it is true, may by animated and masterly demonstrations, do much to guide and assist the anatomical Student in the prosecution of his studies, but it is in the Dissecting Room, with the dead body before him, by patient and assiduous dissection, that the Student can alone acquire a knowledge of Anatomy." (Annual Announcement, Jefferson Medical College, Philadelphia, 1832, pp. 4-6.)

Unfortunately here, as in so many other institutions, the time of the professor was soon so taken up by private practice that he was unable to devote that personal attention to his classes in dissection necessary for the best results.

Other well known professors at the Jefferson Medical College have been, J. Pancoast, W. H. Pancoast, and W. S. Forbes.

Of the considerable number of *private schools organized in Philadelphia* (J. Parish and R. Harlan, in 1818, T. Hewsen, in 1822, Dr. G. McClellan, in 1829, all started schools of this kind), the most celebrated is the Philadelphia School of Anatomy, which lasted from 1820 to 1875.

W. W. Keen has given in his "*History of the Philadelphia School of Anatomy*," 1875, a most interesting account of this important school. It accomplished a great mission. "Within its walls earnest, intelligent laborious men of science taught, experimented and investigated, and published the results of their work in many a book and pamphlet, while thousands of men who studied and dissected there, and there began their scientific lives, are spread all over the country, and in fact all over the world, doing the best of work as practitioners, teachers, writers, and original investigators."

The School was opened in 1820 as the private anatomical school of J. V. O. Lawrence (1791-1823), under the name of the "Philadelphia Anatomical Rooms." "At that time the University (then the only medical school) closed its doors in April and they remained unopened till November. . . . To fill out this long hiatus Lawrence, a graduate of the University of Pennsylvania, opened his school and gave a course in Anatomy and Surgery, which began in March, had a recess in August, and ended in November. He gave six lectures a week. In 1822 he was made assistant to Dr. Horner, then Adjunct Professor of Anatomy at the University of Pennsylvania." "Like most of his followers in the school, not satisfied with teaching, he was also a frequent writer as well as active in original investigations and experiments." In 1822, assisted by Drs. Harlan and Coates he performed over ninety experiments on animals to test the absorbent action of the veins and in the following year over one-hundred.

The second head of the school was Dr. John D. Godman, who previously has been professor of anatomy in the Medical College of Ohio. Dr. Godman retired from practice in 1823 when he began teaching in the School. As was the custom for many years afterwards he gave three courses a year, viz.: the autumn course, twice a week from September to November; the winter course, four times a week from November to March; and the spring course, twice a day (with a view to graduation) from March 1 to April 1; the remainder of the year being a vacation in teaching, but devoted to work. The fee for each course was ten dollars." In 1824 Godman established in connection with the school a reading-room and library. Dr. Godman was one of the founders of the *American Journal of the Medical Sciences* and published in three volumes a "*Natural History of American Quadrupeds*," and among many other works a book on the "*Fasciae*," one on "*Physi-*

ological and Pathological Anatomy," and a paper on "Arterial and other Irregularities." Dr. Godman was called to Rutgers College in 1826 and was succeeded by Dr. James Webster, who in 1830 was called to the Geneva Medical College.

In 1831 Dr. Joseph Pancoast re-opened the rooms and taught there for seven years. In 1838 he became professor of anatomy in the Jefferson Medical College. He translated and edited several foreign books and prepared a new edition of Horner's Anatomy while at the Philadelphia School.

Dr. Pancoast was succeeded by J. Dunot and J. M. Allen, the latter of whom published a Dissector's Manual. The first woman to dissect there joined the class in 1843-4. "'It was probably,' says her sister, 'the first time that a woman had dissected as a medical student.'"

Dr. D. Hayes Agnew assumed the responsibilities of the school in 1852 and held it for ten years. He was found a most inspiring teacher. "While teaching here he published his "Dissector's Manual" and a series of papers on Anatomy in its Relation to Medicine and Surgery. In 1862 Dr. Agnew relinquished the anatomical department to Dr. J. E. Garretson, who was followed in turn by J. P. Andrews and R. S. Sutton and finally by W. W. Keen who once more reestablished the brilliant reputation of the school as may be judged from the following quotation from his farewell speech:

"It ill becomes one to speak of himself, but I may perhaps be permitted to state the following facts: I have lectured here longer than any of my predecessors, Allen and Agnew only excepted; I have given nine winter and five summer courses of Descriptive and Surgical Anatomy, two courses on Artistic Anatomy, and thirteen courses on Operative Surgery, besides private courses to numerous individual students and graduates. I have had nearly fifteen hundred students of whom at least five are already professors in medical colleges, and one has opened the first dissecting-room ever established in Japan. They have come from the District of Columbia, and every State in the Union, except New Mexico and Nebraska, and from fourteen foreign countries, as follows: Canada, Nova Scotia, Prince Edward's Island, New Brunswick, Cuba, Porto Rico, Mexico, Costa Rica, Nicaragua, Denmark, Norway, Prussia, Switzerland, and England.

"From 1866 to 1870 I occupied only the western building, Dr. Richardson having the lower story of the other for his Quiz Class, and Dr. H. Lenox Hodge, from 1868 to 1870, the upper story for his courses in Operative Surgery, but in order to accommodate my increasing classes I was obliged, in 1870, to obtain the use of both buildings, and later still

further to enlarge the lecture-room by placing the gallery over my head, while many, even then, were unable to obtain seats. During this time, also, I have published a series of Clinical Charts of the Human Body, a sketch of the Early History of Practical Anatomy, and a pamphlet on the Anatomical, Pathological, and Surgical Uses of Chloral (which I deem my most important contribution to practical Anatomy). I have edited also Flower's Diagrams of the Nerves and Heath's Practical Anatomy, and have published anatomical and surgical papers on a new diagnosis of Fracture of the Fibula, on the Anatomy of Optic Chiasm (with Dr. William Thomson), on the Ossification of the Atlas Vertebra, on a case of Asymmetry of the Skull, on a Malformation of the Brain, on the Physiology of the Inferior Laryngeal Nerves and the Intercostal Muscles in a case of judicial hanging, and numerous other general medical articles, besides gathering the material for several other papers and perhaps more extended publications." (History of the Philadelphia School of Anatomy, by W. W. Keen, Philadelphia.)

Among others more or less closely associated with the Philadelphia School of Anatomy during the last twenty-five years of its existence were J. F. Meigs, the well known obstetrician, S. Weir Mitchell, who began his work on snake venom in the building occupied by the school, and "with G. R. Morchouse discovered the extraordinary chiasm in the inferior laryngeal nerves in chelonia," and Dr. Brinton, who discovered a method of preserving fresh anatomical specimens by applying gutta-percha dissolved in benzole, published an excellent paper on dislocations of the sternum and discovered the right spermatic vein. Harrison Allen also carried on some of his studies in comparative anatomy in the building occupied by this school. Many of the foremost physicians of this country received an important part of their training at the school. It was the one institution for medical education in this country previous to very recent years where scientific research held real position. Even medical students were encouraged to investigate. Thus the valuable statistical study of the brachial plexus made by Walsh (Am. Jr. Med. Sc., 1877, vol. LXXIV, p. 387) was begun here at Keen's suggestion.

At the Pennsylvania Medical College (the medical department of the Pennsylvania College at Gettysburg) which was founded in Philadelphia in 1839 and discontinued in 1861, S. G. Morton was professor of anatomy 1839-43. Morton gathered together a splendid collection of skulls and published among other works "Crania Americana," 1839, *Crania Aegyptiaca* (1844), *Ethnology and Archaeology of the American Aborigines*, 1846, and an *Illustrated System of Human Anatomy*, 1849.

At *Harvard*, John Warren, from 1782 to 1815, and John Collins Warren from 1815 to 1843, were professors of anatomy and surgery, and O. W. Holmes, from 1847 to 1882, professor of anatomy and physiology. The two Warrens, although men interested in surgery rather than in anatomy, were men of broad interests and did much to build up the anatomical museum now named after John Warren.

T. Dwight, who has been professor of anatomy there since 1883 has been an active contributor on anatomical subjects (see note 21).

Corydon La Ford, professor of anatomy at Michigan, from 1854 to 1893, was much liked as a teacher. Previous to the adoption of the graded course he gave instruction in several institutions successively each year. This he continued to do for a time in spite of the fact that his salary was raised in order to make it unnecessary for him to teach elsewhere. (Vid. *Am. State Universities and the Univ. of Mich.*, 1875, p. 264.)

For an account of the early history of anatomy in this country, in addition to the two papers by W. W. Keen, "A Sketch of the Early History of Anatomy," 1874, and "the Philadelphia School of Anatomy," 1875, reference may be made to E. M. Hartwell's "Study of Human Anatomy" (Studies, Biological Laboratory, Baltimore, 1881), and "Hindrances to Anatomical Study in the United States" (Annals of Anatomy and Surgery, Brooklyn, 1881), and Carson's "History of the Medical Department of the University of Pennsylvania."

17. (p. 97). MICROSCOPIC ANATOMY.

American anatomists played no part in that early development of histology, embryology, and cytology which in the hands of the European and especially the German anatomists contributed during the middle of the last century so greatly to the advancement of practical medicine no less than of pure science. A little of this new knowledge drifted into this country in a tardy fashion.

Up to 1840 the microscope was so little used in America that when the government exploration expedition, known as the Wilkes Expedition, set forth in 1838, no microscope could be bought in this country and one was borrowed from Dr. P. Goddard of Philadelphia. (Vid. *Debt of American Microscopists to Spencer and Tolles*. Trans. Am. Mikr. Soc., 1901-2.) In 1838 C. A. Spencer announced himself as a manufacturer of microscopes at Canastota, N. Y. Both he and his pupils R. B. Tolles and H. R. Spencer made good instruments and introduced some improvements in the construction of microscopes. Thus

Tolles discovered a method of cover-glass correction for objectives and was the first to use homogeneous immersion lenses.

The microscope during the fourth, fifth, and sixth decades of the last century was, however, for the great bulk of Americans who used it a pretty toy rather than an aid to scientific discovery. For example, "Dr. Cheever has said: 'Dr. Holmes was one of the early microscopists, and was a very good one. The instrument was not among the tools of the instructing physicians when he was studying in Paris (1833-1835), but soon afterwards it came into general use. He brought one home with him from Europe. It fascinated him, as indeed it did many another. He had a great taste for everything ingenious, and playing with this new machine devoured many an hour. He was forever taking his own to pieces and putting it together, and trying all sorts of experiments with it, both as to the mechanism itself, and as to subjects of examination. How well I recollect the intense absorption with which he would thus pass long hours! Hours which were not wasted, for he was no mean authority on this subject in his day.'" (Morse, J. T. *Life and Letters of Oliver Wendell Holmes*, 1896, Vol. I, p. 183.) Thus popular demand led to the construction of elaborate expensive instruments rather than to that of simple serviceable ones. The microscopes made in recent years in America are copied closely after the simple German models.

An exception to the general run of the early American microscopists, Professor Bailey of West Point, early in the forties, achieved marked European distinction for his work on the infusora. S. Wyman likewise in 1843 utilized the microscope with effect in the study of the teeth of *Lepidosteus*. The first mention I find made of the use of the microscope in a medical school is the announcement made in the catalogue of Dartmouth College for 1848 that the professor of anatomy there had a Chevalier microscope for demonstrating the microscopic structure of the tissues. In 1860 the Berkshire Medical School announced that thorough instruction in the use of the microscope would be offered by Professor Stiles, and in 1863 use of the microscope was advertised at the Harvard Medical School. In 1869 the Philadelphia School of Anatomy advertised that "the microscopic anatomy of the various tissues will be shown by the class microscope." At about the same period special instruction in the use of the microscope was offered by the professor of anatomy at the University of Michigan, for a fee of \$5.00. According to His (*Vesalianum*, Basel, 1885, p. 29), the microscope was introduced into the German medical schools in the fifties, yet he himself as a student in one of the larger German universities

had to stand in a line of a hundred men which slowly filed passed a demonstration microscope.

During the sixties the more scientific physicians of the country were making some use of the microscope. Thus about 1860 J. M. Da Costa, while giving private courses in medicine in the building of the Philadelphia School of Anatomy, translated v. Kölliker's *Microscopic Anatomy* from the German. During the seventies demonstration of microscopic structure began to be a regular part of the instruction in the better schools. Thus the Yale catalogue announces for the year 1872 3: "microscopy, histology and pathology, illustrated by a sufficient number of compound microscopes and a large collection of the best preparations. It is believed that no institution in this country furnishes to students greater facilities for acquiring exact knowledge in this department."

Many devices were utilized for demonstrating numerous sections quickly to large numbers of students. Thus for instance in some schools microscopes were placed on a track which ran around on a table at which a section of the class stood or sat. The microscope could in this way quickly be passed from one student to the next.

A thorough training in microscopic anatomy began to be offered only after the establishment of a graded curriculum and then usually rather in connection with pathology than with anatomy. Previous to this time, however, several private laboratories were opened for instruction in microscopic technique. Thus C. Heitzmann, who had been a private docent at Heidelberg, in 1874 opened a private laboratory for microscopic investigation in New York City. Heitzmann was one of the earliest to declaim the inadequacy of the cell theory when applied to certain animal structures. In his laboratory a considerable amount of investigation was done. In a book on the "*Mikroskopische Morphologie des Thierkörper*," published in 1883, he gives a list of the investigators who had studied in his laboratory and of their publications.

18, (p. 98). REFORM IN MEDICAL EDUCATION.

Throughout the long period of low standards of medical education in this country there was much talk of reform at various meetings of medical societies. "In May, 1867, there was held in Cincinnati a convention of delegates from the medical schools of the country and resolutions were passed recommending changes in the methods of study, advising four years of study instead of three. 'These propositions,' says Dr. H. A. Johnson, 'no doubt faithfully represented the opinions

of those teachers when at a distance from their institutions, but they had altogether a different set of ideas when the question was presented in its financial aspects at home.'” (Report Illinois State Board of Health, 1891, p. xxxii.) The Association of American Medical Colleges formed in 1877 likewise failed to bring about a reform.

Meanwhile the establishment of a graded course was initiated by the Chicago Medical College, now the medical department of the Northwestern University. This college upon its organization in 1859 offered a graded course of study extending over three years. Students were, however, allowed to graduate upon hearing lectures for two years. The reform in reality was chiefly brought about by the changes introduced at the Harvard Medical School after Charles W. Eliot became president of the University. In 1871 a three years graded course of nine months each year was established in this school. In 1880 a four years graded course was offered, and after 1892-3 it was required. In the medical department of Syracuse University, opened in 1877, a three years graded course of nine months each year was required; and in the same year the course at the University of Pennsylvania was changed to a three years graded course of five months each year. Michigan adopted the three year course in 1880.

In 1880 the Illinois State Board of Health adopted its schedule of minimum requirements to go into effect after the session of 1882-83. These were in advance of the requirements for a degree at most of the medical schools but still considerably below that of the institutions above mentioned. They required three years of medical study during two years of which courses of lectures must be attended in a medical school of approved standing. The courses must be at least five months long and instruction must include dissection and clinical instruction. In 1887 the standards were raised to take effect in 1891, to four years of medical study with attendance at a medical school during three years of this time. At present attendance at four annual sessions of six months each is required by this board as well as by the State Board of Medical Examiners in a large number of the States. Of these the New York Board has taken the lead in demanding increasingly higher standards. The branches of medical science included in the course are: anatomy, physiology, chemistry, materia medica and therapeutics, theory and practice of medicine, pathology and bacteriology, surgery, obstetrics, gynecology, hygiene, and jurisprudence.

While the State Boards have thus played some part in raising the standards of medical education they have not always shown either fairness or wisdom in the rules they have adopted. Thus for instance the Minnesota Board has made a ruling that colleges giving advanced

standing for work in non-medical colleges are not recognized. If, for instance, a medical school which has the highest standards of education, grants an M. D. degree to a man who has studied there for three years after having previously studied physics, chemistry and biology, including human anatomy and physiology, for four years in a leading non-medical college or scientific school, not only this individual but all other subsequent graduates of that medical school will be debarred from practice in Minnesota. Yet this individual is exceptionally well educated and the other graduates are obviously far better prepared than the majority of those who are examined for their fitness to practice in that State.

Furthermore the State examinations are mere written tests of memory cram, not thorough examinations of fitness for practice. Still on the whole the State Board examinations have worked for the advance of medical education. (An abstract of the State laws regulating the practice of medicine is published by the American Medical Association, Chicago.)

Good work has been accomplished by the American Medical Association, and by the Association of American Medical Colleges, founded in 1890. To this latter association only those colleges are admitted which maintain a certain standard of excellence in their educational requirements and these standards have been rapidly raised since the formation of the society. Special mention should be made of the late Dr. N. A. Davis of Chicago who fought most valiantly to bring about the much needed reform.

The Illinois State Board of Health published in 1891 a valuable pamphlet on Medical Education and Medical Colleges in the United States and Canada. While conditions have been wonderfully improved since the pamphlet was written, there are still far too many schools inadequately equipped with material, men and ideals, and far too few schools where high standards of education and scientific excellence are maintained. (See L. F. Barker, *Medicine and the Universities*, American Medicine, 1902; J. M. Dodson, *The Modern University School*, Journal of the American Medical Association, Sept. 6, 1902; H. L. Taylor, in Parson's "Professional Education in the United States, Medicine," 1900, p. 351, published by the University of the State of New York: Dexter, "History of Education in the United States," 1903.)

The introduction of laboratory methods of instruction in the medical sciences and the development of more practical clinical instruction has caused a demand for a better preliminary education than was previously considered necessary. A four years high school course is now required as a preliminary for entrance into any respectable school. At

Columbia since 1902 about one year of college work has been required. A similar requirement is made at the Cornell Medical School and at the University of Minnesota. At the University of Michigan and at Chicago-Rush Medical School since 1902 about two years have been required. A similar requirement goes into effect next fall at the University of California. At the Western Reserve University since 1901 three years of college work have been required, and at the Johns Hopkins since 1893, and Harvard since 1901, the diploma of a recognized college or scientific school or its equivalent.

For entrance into the Johns Hopkins Medical Department the preliminary work must include a training in French, German and Latin, chemistry, physics and general biology. This is the only institution which, as yet, requires so extensive a preparation, although scientific training in biology, physics and chemistry, as a good preliminary training for medical study, was offered at Harvard University after the establishment of the Lawrence Scientific School in the fifties. Similar opportunities were afterwards offered at other institutions. Special preliminary courses leading up to the study of medicine were established at the Universities of Pennsylvania, Cornell, Yale, Princeton, Lake Forest, Northwestern University, the Johns Hopkins University, the University of Wisconsin and other colleges. As a rule these preliminary courses, usually extending over two years, were found to be over-crowded with subjects. (See Report U. S. Bureau of Education, 1881, and 1892-3, pp. 601-13.)

At Harvard in 1884, 53.9 per cent of the students of medicine were college graduates; in 1889, 34.4 per cent; in 1893, 23 per cent. (Medical Education, Rept. U. S. Bureau of Ed., 1892-3.) This steady decline in the ratio of college graduates to the total number of medical students does not indicate an increasing public appreciation of the value of a college training as a preliminary for medical studies. As a matter of fact most of those institutions which have put up high entrance requirements have suffered a severe loss in the number of attending students. On the other hand Dexter in his "History of Education in the United States," 1903, has pointed out that of those who have made a marked success in medicine a proportionately very large number have graduated from literary and scientific colleges previous to the study of medicine.

19. (p. 98). INTRODUCTION OF LABORATORY METHODS.

Michigan claims the credit of having opened the first laboratories for medical instruction in this country. Chemistry was taught there by

the laboratory methods in the fifties. Laboratory methods in histology and physiology were adopted in 1877 and in hygiene and bacteriology in 1888. At Harvard laboratories for physiology, histology and pathology were opened in 1871 for regular class work, although it was not until a new building was acquired in 1883 that adequate laboratory facilities were furnished in these subjects. During this period from 1871 to 1883 \$320,000 were added to the funds of the medical school by bequests and gifts. This shows the public appreciation of the advanced stand Harvard was taking.

20. (p. 98). SCIENTISTS IN THE MEDICAL SCHOOLS.

In Note 15 we have pointed out that the Philadelphia School of Anatomy served as an active center of research as well as a school of instruction. At the University of Pennsylvania and other institutions some of the instructors were scientifically active men, but in general little encouragement was given to research and what was done was accomplished through much self-sacrifice.

At Harvard H. T. Bowditch, fresh from the scientific atmosphere of Germany, was made assistant professor of physiology in 1871 and professor in 1876. In the catalogue for 1871 and subsequently he offered to 'third class students opportunities for original investigation in the laboratory,' the first published indication in America of university ideals in undergraduate medical education. Harrison Allen, professor of physiology at Pennsylvania, (1878-85), was enthusiastically in favor of research. C. H. Stowell introduced class work in histology, in 1880, and Henry Sewell scientific physiology, in 1883, at Michigan. W. H. Welch at the Bellevue Medical School and T. M. Prudden at Columbia did much to introduce the new German pathology into America in the seventies and early eighties. When Welch became professor of pathology at the Johns Hopkins University, in 1884, he established there a research laboratory which has since served to train several of our leading pathologists and to advance the science in America. At Harvard C. S. Minot during the eighties introduced thorough courses in histology and embryology.

The influence of these men and of several of their contemporaries has since led to a rapid advance of the sciences of physiology, histology, and pathology in the medical schools. Unfortunately, however, human anatomy continued in the main in the hands of surgeons unacquainted with the subject as a science. Only too often histology and embryology have not been thoroughly understood by the professor of anatomy, and

have been either handed over to the physiological and pathological departments or established as separate subjects unco-ordinated with gross anatomy. While it would certainly be a distinct loss if anatomy were not cultivated by physiologists, pathologists and clinicians in those aspects which bear most closely on their fields, it is equally certain that an anatomical department should embrace microscopic anatomy and the study of organic development as well as gross anatomy. Otherwise but a narrow, unproductive attitude toward the science can be maintained.

21, (p. 99). ENDOWMENT OF MEDICAL SCHOOLS.

Since the establishment of numerous well-equipped laboratories and the employment of well trained men to devote their whole time to the care of the laboratories, to teaching and research, the expenses of the better schools have so increased as to make the fees of the students, even when raised to \$200 a year, as at Harvard and the Johns Hopkins University, and \$250, as at Columbia, utterly inadequate to meet the fixed charges. Large endowments or State support are absolutely necessary for a proper system of medical education.

The following table, based upon the Report of the Commissioner of Education, shows the number of colleges and universities, professional and technical schools in the United States in 1875-76 and in 1901-2, the number of instructors, students, and books in the library, and the estimated value of grounds and buildings, amount of productive funds, income from productive funds, income from tuition and fees, state and federal appropriations, and the amount of benefactions for the two years. The figures relative to the number of institutions, students and instructors, are probably fairly accurate. The figures relative to grounds, buildings, endowment and income are but imperfect approximations. So far as possible the number of institutions on which the data are based is given in each instance.

In this table under universities and colleges are included all co-educational institutions and all institutions devoted to the education of men and the higher grade of colleges devoted exclusively to the education of women. All professional schools are included under the respective headings, but only those technical schools of agriculture and engineering which are not university departments are classed as technical schools. The data for the technical schools for 1875-6 are taken from page CXVIII of the Report of that year. It is not, however, perfectly clear that the figures there given under the head of schools of science refer to technical schools as defined above.

TABLE A—NOTE 21.

Year.	Universities and Colleges.	Number reported.	PROFESSIONAL SCHOOLS.					Technical Schools.	Number reported.	Theology	Number reported.	Of Law.	Number reported.	Of Medicine.
No. institutions	355 477	355 477	43 43	43 43	123 148	123 148	43 43	43 43	43 43	123 147	43 102	43 102	80 151	80 154
No. instructors	3,786 9,511	312 177	43 43	415 1,319	118 117	118 117	41 102	615 1,031	224 1,155	615 1,031	80 151	224 1,155	80 151	981 5,029
No. students	26,353 89,030	304 177	43 43	3,619 13,010	116 118	116 118	39 102	5,163 7,343	2,677 13,912	5,163 7,343	73 154	2,677 13,912	73 154	8,580 26,821
No. books in library	1,806,173 9,006,171	288 175	42	43,727 291,981	87 118	87 118	3 70	599,177 1,527,156	52,311 386,905	599,177 1,527,156	42 68	52,311 386,905	42 68	62,970 156,929
Est. value, grounds, bldgs., apparatus	\$11,076,105 180,115,537	321 171	42	\$3,324,109 27,511,362	73 116	73 116	3 27	\$6,268,415 15,405,710	\$45,000 1,670,000	\$6,268,415 15,405,710	59 102	\$45,000 1,670,000	59 102	\$3,154,350 12,486,612
Amount of productive funds	33,252,585 170,111,470	189 438	33	5,591,128 14,451,783	79 100	79 100	21 34	8,415,601 23,038,877	58,201 486,001	8,415,601 23,038,877	38 60	58,201 486,001	38 60	220,266 2,132,568
Income from productive funds	2,453,336 7,612,069	181 421	31	403,945 587,039	77	77	9	529,204	17,635	529,204	38	17,635	38	15,771
Income from tuition and fees	2,136,062 10,527,171	251 416	33	70,093 610,387	33	33	14	52,944	361,552	52,944	52	52,944	52	361,552
State appropriations	367,521 5,100,331	29 413	35	168,277 1,263,999	35	35	35	168,277 1,263,999	168,277 1,263,999	168,277 1,263,999	35	168,277 1,263,999	35	168,277 1,263,999
Federal appropriations	905,413	412	30	1,951,185	30	30	30	1,951,185	1,951,185	1,951,185	30	1,951,185	30	1,951,185
Total income	5,256,919 26,800,162	421	42	672,621 4,796,613	79	79	38	1,414,721	522,763	1,414,721	70	522,763	70	41,356,600
Benefactions	16,307,301	281	426,783	426,783	66	66	24	1,269,433	52,859	1,269,433	48	52,859	48	160,584

¹ In addition there are 2,281,478 pamphlets. ² In addition there are 140,312 pamphlets. ³ Federal and state appropriations are probably here combined. ⁴ Figures for 1901. The figures given in the report for 1902 are more incomplete.

In number during the period under consideration the schools of law were more than doubled, those of medicine nearly doubled, the colleges and universities increased about a third, the schools of theology about a sixth and the independent technical schools apparently remained constant.

The number of instructors increased over five-fold in the medical schools, about five-fold in the law schools, over three-fold in the technical schools, less than three-fold in the universities and colleges and less than two-fold in the theological schools.

The number of students increased about five-fold in the law schools, nearly four-fold in the technical schools, over three-fold in the universities and colleges, about three-fold in the medical schools and less than fifty per cent. in the theological schools.

In 1870 the population of the country according to the United States census was 38,558,371; in 1880, 50,155,783; in 1890, 62,622,250; and in 1900, 76,303,387. During the period under consideration, 1876-1902, it is safe to assume that the population less than doubled. The number of those seeking a higher education has therefore increased much faster than the population, in spite of rapidly increasing standards of the universities and professional schools.

The data relating to the libraries, value of equipment and grounds, endowment funds and income are so incomplete that comparisons similar to those given above cannot be well made. It is evident, however, that great progress has been made in all of these directions. The most favored institutions are the technical schools, the income of which seems to have increased perhaps seven-fold, although the number of students increased but four-fold. The income of the law schools increased with a similar rapidity but in them the increase in the number of students was more rapid. In proportion to the increase in the number of students the income of the colleges and universities has increased more rapidly than that of the medical schools.

From the United States Census for 1900 (Statistical Atlas, plates 128 and 180) it may be estimated that the value of farm lands doubled during the period under consideration (from nine to eighteen billions) and that of capital invested in manufactures increased four-fold (from two and a half to ten billions of dollars). It is certain, I think, that the value of the equipment, buildings and grounds and that of the productive funds of institutions for the higher education has increased in a ratio greater even than that of the capital invested in manufactures. The evident rapid increase in the vested funds devoted to medical education is one of the most encouraging features.

The success that has followed the endowment of a hospital for med-

ical teaching by Johns Hopkins and for the associated medical school by Mary Garrett and others; the gifts to the medical departments of Columbia University, at New York, and the Western Reserve University, at Cleveland; the more recent endowments of the medical departments of Cornell University at Ithaca, N. Y., and of Tulane University at New Orleans; the gifts for the medical science building at Pennsylvania, the establishment of the Rockefeller Institute and the recent magnificent gifts for the Harvard Medical School, it is to be hoped indicate a tendency on the part of public spirited citizens to endow medicine as it should be endowed. We must also expect far more liberal support from the State. In no way does the public pay more dearly for its lack of liberal support of educational institutions than in its attitude toward medicine. It is a debt paid not only with money but with life. (See W. H. Welch, Higher Medical Education and the Needs of its Endowment, *Medical News*, July 21, 1894; L. F. Barker, *Medicine and the Universities*, *American Medicine*, 1902.)

TABLE B, NOTE 21.

University.	Situation.	Number of Professors.	Number of Instructors.	Number of Students.	Value of grounds and buildings.	Value of endowments.	Annual income.	Tuition.
Harvard ¹	Boston, Mass	32	111	506	\$600,000	\$1,000,000	\$163,070	\$200
Columbia	New York	36	66	827	2,250,000	478,227	419,000	200
Johns Hopkins ² . .	Baltimore, Md. . . .	18	21	129	171,000	426,866	463,000	200
Western Reserve . .	Cleveland, Ohio. . . .	26	18	126	300,000	200,000	26,000	125
Pennsylvania	Philadelphia, Pa . . .	28	43	542	....	?	4120,000	200
U. of California . .	San Francisco, Cal . .	19	20	140	300,000	?	25,536	150
Northwestern	Chicago, Ill.	38	15	465	225,000	50,000	63,913	135
Rush ³	Chicago, Ill.	22	115	792	375,000	?	65,000	137

¹ Harvard University has under construction a set of five buildings which will far exceed in beauty and fitness any at present in this country. The buildings are expected to cost \$1,800,000 and the equipment \$50,000. An endowment fund of about \$3,000,000 has likewise been provided for. Of the large sum of money which it was necessary to raise for the buildings and toward increasing the endowment, Mr. J. P. Morgan contributed \$1,135,000, Mr. J. D. Rockefeller \$1,000,000, Mrs. A. D. Huntington \$250,000, Mr. J. Stillman \$100,000 and numerous generous friends of the college have made up the remainder. (Vid. Report of the President and Treasurer for 1901-2.)

² The Johns Hopkins Hospital, with an endowment of \$3,500,000, is essentially a part of the school.

³ The first two years of a four year course are spent at the University of Chicago.

⁴ Unofficial estimate.

The majority of the medical schools have no endowment and considering the wealth of the country there is as yet no school endowed as liberally as it should be, no institution adequately supported by the State. The preceding table indicates the number of students studying

medicine, the number of professors and instructors, the estimated value of the buildings, and the total income of a few of the best supported schools in 1901-1902. It is based primarily on the Report of the Commissioner of Education for 1902. In several of the institutions there has been a marked decrease in the number of students since that date. This is owing in part to higher standards of admission.

At the other end of the scale are such institutions as the Knoxville Medical School with eight professors, two instructors, twenty-one students, a tuition fee of \$37.00 and a total annual income of \$790.00, and the Woman's Medical College, Baltimore, with sixteen professors, eight instructors, twenty-five students, and an annual income of \$1,818.00.

Unfortunately the majority of educational institutions either publish no financial reports or, like most of the State universities, publish them in such a form that no adequate knowledge can be gained of the funds and running expenses of the various departments.

22, (p. 99). SCIENTIFIC ANATOMICAL LABORATORIES IN MEDICAL SCHOOLS.

(A) PRODUCTIVENESS.

In Note 15 I have spoken of the scientifically productive anatomists who held chairs in medical schools previous to the eighties. Of recent years the number of such men has greatly increased.

At *Harvard* T. Dwight was instructor in histology and later in topographical anatomy previous to becoming professor of anatomy in 1883. Professor Dwight has been a more extensive contributor to the science of human anatomy than any of his predecessors in this country, and has used more extensively than heretofore the material of the dissecting room for scientific studies of variation, especially in the fields of the muscular and skeletal systems. He has added extensively to the anatomical museum and has established a valuable collection of skeletons to illustrate structural variation. He was also the first in the country to make use of frozen sections of the body and in his laboratory S. F. Mixer introduced digestion for the corrosion of injected specimens. Among others who have contributed from Professor Dwight's laboratory may be mentioned S. W. Allen, E. A. Codman, assistant in surgery, *Harvard*, F. Dexter, H. A. Lothrop, instructor in surgery, *Harvard*, R. W. Lovett, assistant in orthopedics, *Harvard*, H. P. Mosher, assistant in anatomy, *Harvard*, O. K. Newell, B. Tenney and J. Warren, demonstrator of anatomy, *Harvard*.

C. S. Minot, who became instructor of histology and embryology in 1883, assistant professor in 1887, and professor in 1892, was the first in this country to give these subjects their proper position in the medical curriculum, and among the first to encourage by example advanced research in these fields. He has done much to advance the study of morphology not only in medical schools, but also in the collegiate departments of our universities. The collection of vertebrate embryos prepared for microscopic study under Dr. Minot's direction at the Harvard Medical School is probably the best and most complete of its kind in the world. The use of this collection is freely offered to trained investigators. Among those who have made contributions from Professor Minot's laboratory may be mentioned R. T. Atkinson, J. F. Bower, J. L. Bremer, instructor in histology, Harvard Medical School; F. Dexter, A. C. Eycleshymer, professor of anatomy, the University of St. Louis; F. T. Lewis, instructor in histology, the Harvard Medical School; G. C. Price, assistant professor of embryology, Leland Stanford University; A. Shaper, professor of anatomy, the University of Breslau, Germany; F. A. Woods, E. Taylor and J. Warren.

At the *University of Michigan*, G. C. Huber, who became assistant demonstrator of histology and embryology in 1887, assistant professor in 1893, and professor in 1902, and J. P. MacMurrich, professor of anatomy since 1893, have made the anatomical laboratories there noted for their scientific productions. Lydia M. DeWitt, instructor in histology and embryology, has likewise done important work. A. H. Roth, R. C. Bourland and E. W. Adamson have also contributed.

At the *University of Pennsylvania*, G. A. Piersol, demonstrator of histology and embryology, 1884-89, professor, 1889-91, and professor of anatomy, 1891-, has contributed to embryology and teratology and is the author of a favorite text-book on histology. From 1901 to 1904 E. H. Gregory, now professor of anatomy at the Northwestern University, was assistant professor of anatomy.

At *Columbia*, G. S. Huntington, assistant demonstrator of anatomy, 1886-89, lecturer, 1889-1890, and professor since 1892, has been the first in the country to realize the full importance of comparative anatomy to human anatomy and has built up a splendid museum for the purpose of instruction and research. Among those who have made contributions from this laboratory may be mentioned J. A. Blake, instructor in surgery, Columbia; C. Carmalt, assistant demonstrator of anatomy, Columbia; B. B. Gallaudet, instructor in surgery, Columbia; A. Hrdlicka, curator of anthropology, National museum; E. A. Spitzka; and A. S. Vosburgh, assistant demonstrator of anatomy, Columbia.

The value of a museum for medical instruction has been treated of

by Professor Huntington in *Science*, vol. 9, 1899; vol. 13, p. 601, 1901, and *Am. Journal Med. Science*, 1898.

Since 1890 many appointments to professorships in anatomy, histology and embryology have been given to men whose aim is to advance the subject in its scientific aspects.

Among them may be mentioned in addition to those named above, R. D. Whithead, professor of anatomy, the University of North Carolina, 1890; W. Keller, professor of anatomy, Texas, 1892; T. G. Lee, professor of histology and embryology, Minnesota, 1892; F. P. Mall, professor of anatomy, the Johns Hopkins University, 1893; R. J. Terry, professor of anatomy, Washington University, St. Louis, 1895; W. S. Nickerson, assistant professor of histology, Minnesota, 1897; A. T. Kerr, professor of anatomy, Cornell, 1898; C. M. Jackson, professor of anatomy, Missouri, 1899; R. G. Harrison, associate professor of anatomy, Johns Hopkins University, 1899; L. F. Barker, professor of anatomy, Chicago, 1900; R. R. Bensley, assistant professor of anatomy, Chicago, 1901; J. L. Flint, professor of anatomy, and I. Hardsty, assistant professor, California, 1901; A. C. Eycleshymer, professor of anatomy, University of St. Louis, 1902; G. H. Hoxie, assistant professor of anatomy, Kansas, 1902; F. C. Waite, assistant professor of histology and embryology, Western Reserve University, 1902; B. G. Meyers, associate professor of anatomy, University of Indiana, 1903; A. C. Pohlman, assistant professor of anatomy, University of Indiana, 1904; E. H. Gregory, professor of anatomy, Northwestern University, 1904; W. H. Lewis, associate professor of anatomy, Johns Hopkins University, 1904.

The next step in advance has come from offering the positions of demonstrators, instructors and assistants to young men interested rather in the development of the science than in exploiting it for the sake of surgery. The establishment of a well endowed school in connection with the Johns Hopkins University gave Professor Mall this opportunity which he has utilized most successfully. His example has been followed in a number of other institutions and is likely to be followed in all the better schools. Research on the part of graduates and undergraduate students of the medical schools has at the same time been greatly encouraged.

The following in addition to Professor Mall have made scientific contributions from the anatomical laboratory of the Medical Department of the *Johns Hopkins University*: C. R. Bardeen, professor of anatomy, the University of Wisconsin; L. F. Barker, professor of anatomy, the University of Chicago; R. B. Bean, assistant in anatomy, Johns Hopkins University; H. M. Berkely, clinical professor of psychiatry, Johns Hopkins University; J. M. Berry; C. E. Brush; H. A. Christian, instructor

in pathology, Harvard Medical School; W. J. Calvert, assistant professor of medicine, the University of Missouri; J. G. Clark, professor of gynecology and obstetrics, the University of Pennsylvania; A. W. Elting; J. M. Flint, professor of anatomy, the University of California; H. A. Fowler; R. G. Harrison, associate professor of anatomy, the Johns Hopkins University; P. K. Gilman; G. L. Hendrickson; M. Herrington; E. C. Hill; J. M. Hitzrot; A. G. Hoen, professor of pathology, Richmond, Va.; A. T. Kerr, professor of anatomy, Cornell University; W. B. Johnson; H. McE. Knowler, instructor in anatomy, Johns Hopkins University; W. H. Lewis, associate professor of anatomy, the Johns Hopkins University; E. L. Mellus; J. B. MacCallum, associate professor of physiology, the University of California; A. W. Meyer; B. D. Meyers, associate professor of anatomy, the University of Indiana; A. G. Pohlman, assistant professor of anatomy, the University of Indiana; R. L. Randolph, professor of ophthalmology, the Johns Hopkins University; F. R. Sabin, associate in anatomy, the Johns Hopkins University; Dr. E. Stieren; G. L. Streeter, instructor in anatomy, the Johns Hopkins University; M. T. Sudler, instructor in anatomy, Cornell University; G. Walker, instructor in surgery, the Johns Hopkins University; R. G. Whitehead, professor of anatomy, the University of North Carolina; H. M. Young, associate professor of surgery, the Johns Hopkins University. (For a description of the anatomical courses and laboratory of the Johns Hopkins University see articles by Mall, Barker, Bardeen, and Hoen, in the *Johns Hopkins Hospital Bulletin*, May-June, 1896.)

At the *University of Chicago* studies in normal anatomy are carried on in the anatomical department, the neurological department and the zoological department. In addition much of the work done in the physiological, pathological and botanical departments has bearing on anatomical problems. All of these departments have been in operation since the founding of the University in 1892. The anatomical department was at first placed in charge of Professor F. P. Mall. In 1893 Professor Mall took charge of the anatomical department of the Johns Hopkins University and anatomy at Chicago was placed in charge of A. C. Eycleshymer. The department was re-organized with L. F. Barker as professor of anatomy in 1900, when the University entered into affiliation with the Rush Medical College and established a four year course of which the first two years are given at the University. Among those who have made contributions from the anatomical laboratory in addition to Professor Barker may be mentioned R. R. Bensley, assistant professor of anatomy, the University of Chicago; A. C. Eycleshymer, professor of anatomy, University of St. Louis; J. M. Flint, professor of anatomy, the University of California; I. Hardesty, associate professor

of anatomy, the University of California; P. Kyes, assistant professor of anatomy, the University of Chicago; D. D. Lewis, J. G. Wilson and D. G. Revell, instructors in anatomy, the University of Chicago; G. E. Shambaugh; F. C. Waite, professor of histology and embryology, Western Reserve University; and R. D. Whitehead, professor of anatomy, the University of North Carolina.

The neurological department, under the direction of Professor H. H. Donaldson, is the foremost center for neurological research in the country. Among those who have made valuable contributions from his laboratory may be mentioned Elizabeth H. Dunn, S. Hatai, I. Hardesty, C. E. Ingbert, S. W. Ranson, J. R. Slonaker, and Helen Thompson. This list includes only those who have contributed several important articles.

The zoological department which has likewise been a most active center for anatomical research is treated more fully in note 32.

For the following account of anatomy at Cornell I am indebted to Prof. S. H. Gage:

At the opening of *Cornell University* in 1868 provision was made for teaching and investigation in Comparative Anatomy and Zoology. The professor at the head of the department (B. G. Wilder, appointed in 1867) also gave instruction to freshmen in all courses in physiology and hygiene. From the beginning the work in anatomy included a study of human osteology and the dissection of preserved human material (mostly still-born children) as well as the study and dissection of the lower animals. Some of Professor Wilder's earlier papers dealt with comparisons of human and animal structures and philosophical considerations in morphology and teleology. (A list of Dr. Wilder's scientific publications down to 1893 may be found in the Wilder Quarter Century Book, the first American Festschrift presented to a teacher by his pupils.)

In tracing the history of the original department four special aims seem to have been dominant: (1) to give the best possible elementary instruction to beginning students; (2) to encourage those especially interested to do advanced work and to undertake the investigation of special problems; (3) to so combine the study of human and comparative anatomy that those aiming to become physicians could most intelligently and successfully pursue their later medical studies; and (4) the establishment of independent departments with the growth of the university.

At the present time (1905) the work once included in the original department is carried on by seven independent departments as follows:

(1) the original department founded in 1868 and now designated the department of Neurology and Vertebrate Zoology. It is still under the direction of Professor Wilder. (2) The department of Entomology and Invertebrate Zoology, directed by Professor J. H. Comstock, founded in 1882. (3) The department of Histology and Embryology, under the direction of Professor S. H. Gage. This department became partly independent in 1885-86 and wholly so in 1895-96. (4) The department of Veterinary and Comparative Anatomy under the direction of Professor G. S. Hopkins, founded in 1896. (5) The department of Comparative Physiology, under the direction of Professor P. A. Fish, founded, 1896. The departments of Veterinary Anatomy and Comparative Physiology (4, 5 above) were also a part of the original chair of Veterinary Medicine founded in 1868. These two independent departments were made possible by the establishment of the New York State Veterinary College upon the Cornell Campus. (6) The department of Human Anatomy, founded in 1898 and conducted for the first two years by Dr. L. Coville and since 1900 by Professor A. T. Kerr. (7) The department of Physiology founded in 1898 in connection with the Medical College and conducted first by Dr. P. A. Fish and since 1903-4 by Professor B. F. Kingsbury. The establishment of the independent departments of human anatomy and physiology in Ithaca was made possible by the foundation of the Cornell University Medical College in New York city, and the duplication of the first two years at Ithaca.

The published work of the original department includes the numerous papers in scientific periodicals and articles in encyclopedias by Professor Wilder and S. H. Gage, and papers on anatomical and zoological subjects by W. S. Barnard, S. H. Gage, F. L. Kilborne, T. B. Stowell, Tracey E. Clark, P. A. Fish, H. W. Norris, G. S. Humphrey, Ida H. Hyde, B. F. Kingsbury, S. E. Meek, B. B. Stroud and H. D. Reed. From the department of Entomology and Invertebrate Zoology, the first independent department to bud off, have originated important books on entomology and bulletins upon economic entomology and papers on insect embryology and morphology.

In addition to the important publications from the department of Histology and Embryology by S. H. Gage papers have been published by Theobald Smith with S. H. Gage, T. B. Spence, G. S. Hopkins, Leonard Pearson, H. E. Summers, B. L. Oviatt, Susanna Phelps Gage, Edith J. Claypole, Agnes M. Claypole, B. F. Kingsbury, R. O. Moody, J. G. Needham, W. A. Hilton, W. F. Mercer, Marguerite Hempstead, Louise Katz, J. M. Berry, Isabella M. Green, Mary J. Ross, B. D. Myers, Gertrude A. Gillmore.

From the department of Veterinary and Comparative Anatomy papers have been contributed by G. S. Hopkins and M. J. Ross.

From the department of Comparative Physiology besides manuals and papers dealing with physiology and pharmacology, there are anatomical papers by P. A. Fish, A. T. Kerr, and M. T. Sudler.

From the department of Physiology, anatomical papers have been published by B. F. Kingsbury.

In New York the work done in gross anatomy falls in one department while that done in histology is under the department of pathology. The undergraduate courses include normal histology under J. S. Ferguson, embryology under I. Strauss and the histology of the nervous system under M. G. Schlapp.

In addition to papers by Dr. Ferguson and Dr. Schlapp articles on anatomical subjects have been contributed by Professor J. Ewing, head of the department of Pathology.

Both Dr. George Woolsey, Professor of Anatomy, and J. S. Haynes, Professor of Practical Anatomy, have published papers from the New York department of gross human anatomy.

Of the anatomical laboratories in medical schools which have recently exhibited scientific activity, that of J. L. Flint at the *University of California* deserves especial mention.

The passing over of the anatomical departments of our schools into the hands of men professionally devoted to the subject marks a step in advance not only from the standpoint of scientific progress but also from that of the education of the medical student. Only those who are themselves endeavoring to advance a subject can realize the progress that others are making. A mere teacher drills in the beliefs of yesterday rather than in the knowledge of today.

While the increase in scientific activity in the laboratories devoted to the anatomical sciences in the various institutions is certainly encouraging it is still far from what it should be. Probably 500 individuals are engaged in teaching anatomy in the 166 medical schools of the country and it may be estimated that probably over \$500,000 a year is expended for the various anatomical courses maintained. In less than twenty-five institutions is scientific research seriously attempted in the anatomical departments of the medical schools. Among these may be mentioned the University of California, Chicago (Rush), Columbia, Cornell, Harvard, Indiana, the Johns Hopkins, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Carolina, Pennsylvania, St. Louis, and Texas.

(b) Nature of Instruction.

The nature of the instruction in human anatomy given in this country has been thus recently summed up by F. P. Mall:

"It is possible to classify the teaching of anatomy in America under four heads.

"The first and lowest order is found in those schools which give a course of crude lectures on anatomy with a dissecting-room in which the work is not directed, but is done in a superficial way. Often the students do not dissect at all. At best they use a brief guide or a quiz compend which enables the student to 'learn enough' to pass the examinations.

"The teaching of anatomy is of a higher order when it follows closely some text-book, especially Gray, when it has lectures and recitations and enough work in the dissecting-room to enable the student to identify the grosser structures, thereby giving enough information to enable the student to pass State examinations. Most of the medical students desire courses of this order.

"In a third and higher order of medical school, about twenty or which may be counted, the course is given to aid the student in their subsequent medical studies. Practical things are pointed out in lectures, and emphasized again in the dissecting-room, and finally the student is examined upon them. Both students and teachers work pretty hard, and at the end of the course all feel that much good has been done.

"In the fourth order of anatomical course it is considered that there are others to be satisfied besides the teachers in a few practical branches—there are teachers in the other sciences, physiology, neurology, pathology, as well as anatomy itself. A student told me recently that he had been studying one thing to help him in another all of his life, and he was dead tired of it; he now desired to study things that were worth studying for their own sake. For him anatomy could not be considered an ancillary science. In presenting a science to students no attitude can be defended, except that in which the science is studied for its own sake. In so doing the development of the student cannot possibly be ignored, for understanding and self-development go hand in hand." (J. H. U. Hospital Bulletin, vol. XVI, No. 167, February, 1905.)

(c) *Expenses.*

Comparatively few educational institutions publish detailed accounts of income and expenditure. It is unfortunate that the policy of secrecy is so prevalent in their financial administration. Those universities which like Harvard and Columbia publish full statements of receipts and expenditures certainly seem to gain the confidence of those wealthy members of the community who desire to aid educational advancement. The State universities likewise publish more or less full accounts of receipts and expenditures but as a rule in so cumbersome a form that it is difficult to gain insight into expenditures for specific purposes.

In thirty-six medical schools about \$250,000 a year is spent on gross and microscopic anatomy and on histology. It seems quite probable that the other 130 schools spend an equal sum, if not much more, upon that subject.

At the *Harvard Medical School* there is a department of "anatomy" with a professor, an assistant professor, a demonstrator and seven assistant demonstrators, and a department of histology and embryology with a professor, two instructors and three assistants. In addition there is a curator of the anatomical museum. Although no specific itemized salary list is published (for the whole medical school the salaries for instructors amounted in 1902-3 to \$102,091.66) it is safe to estimate the amount paid for salaries for anatomical instruction at about \$20,000. Two special janitors and a technician are employed at a cost of not much less than \$2,000. The appropriations for the year 1902-3 for laboratory supplies and apparatus were for "anatomy" \$2,750.00, histology and embryology \$1,186.45, and for the museum \$312.00. For some of the other departments they were as follows: chemistry, \$1,232.39; physiology, \$4,307.41; pathology, \$800.00. The accounts of the various laboratories of the scientific departments at Cambridge are not published in such form that comparison with the figures of the anatomical department is made easy. The payments for the Museum of Comparative Zoology were \$42,082.36. In addition appropriations were made for the zoological department.

At *Columbia University* for the year 1902-3 in the anatomical department (human and comparative vertebrate anatomy) the salaries of the instructional force (a professor, a demonstrator and eight assistant demonstrators) amounted to \$18,281.25. For supplies \$3,292.12 was granted and for special service (a technician, an artist and three janitors) \$3,240.00. Histology is there given in the pathological depart-

ment for which the following appropriations were made: salaries, \$28,094.40; supplies, \$2,392.76; apparatus, \$197.57. For physiology the following sums were allowed: salaries, \$13,099.99; supplies, \$950.54; laboratory equipment, \$455.93; table at Woods Hole, \$100.00. In the zoological department of the University \$16,450.60 was allowed for salaries, \$1,199.66 for apparatus, and \$78.33 for special purposes. In the botanical department \$8,324.96 was given for salaries and \$599.54 for supplies.

At *Chicago University* although no detailed account of expenditures is published the departments devoted to the anatomical sciences are run on a scale at least fully as liberal as those at Harvard and Columbia. There are in the department of anatomy a professor, two assistant professors and seven instructors and assistants; in the department of neurology a professor and two associates and an assistant; and in the department of embryology an associate professor and one or more instructors. In these laboratories an artist and several technicians and special janitors are employed. The total running expenses probably amount to over \$40,000.

The *Johns Hopkins University* publishes no account of its yearly expenditures. There are on the teaching staff of the department of anatomy (gross human anatomy, histology and embryology) a professor, two associate professors, an associate, two instructors and several assistants. The total amount paid for salaries is a little over \$12,000. A technician and two janitors are employed in addition to an engineer and occasional extra service. For these the salaries must amount to \$2,000. Four thousand dollars may be counted for laboratory expenses. Thus the total yearly expenditures at this university amount to nearly \$20,000.

Cornell University offers instruction in anatomy both at Ithaca, N. Y., and in New York city. At Ithaca there is a professor of neurology, one of histology and embryology and one of anatomy, and in addition there are (1904-5) eleven instructors and assistants in the various laboratories devoted to the above subjects. At New York there are two professors and an instructor in anatomy, two instructors in histology, and one in embryology, and eleven demonstrators and assistants in anatomy and histology. The total cost of running these various departments must be considerably over \$25,000. At New York histology is given in the department of pathology.

At the *endowed universities* in which the most scientific research is carried on, the yearly expenses in the departments devoted to anatomy in the medical school may be said to range from \$20,000 to \$40,000. In the leading medical schools of the State universities less is spent

on anatomy but in them research is confined in the main to the hard working members of the teaching staff.

At the medical school of the *University of Minnesota* anatomy is taught in two separate but co-ordinated departments, that of "anatomy" and that of "histology and embryology." In the former there are a professor, a demonstrator and a prosector. For the year 1901-2 the salaries of the staff of instruction amounted to \$3,300 and the appropriations for the laboratory to \$3,070.14. In the department of embryology and histology there are a professor, an assistant professor, an instructor and an assistant. In 1902 the salaries of the staff of instruction amounted to \$5,256.27 and the appropriation for the laboratory to \$2,490.49. A special janitor and part of the services of a carpenter and a mechanic are at the disposal of the two departments. If \$1,500 be counted for service, the total amount appropriated for anatomy at this university, exclusive of heat, light, etc., amounted in 1901-2 to over \$15,000. In addition courses in comparative anatomy and histology are given in the biological department. The appropriations for this and various other departments of the University for the year 1901-2 were as follows: Botany: salaries \$4,690, bills \$4,175.37; biology: salaries, \$5,185, bills, \$911.14; physiology: salaries \$3,476.26, bills \$2,384.20.

At the *University of Michigan* there are two co-ordinate departments, one of "anatomy" and one of "histology and embryology." In the former there are a professor, two instructors and four student assistants; for the latter a professor and an instructor. A specific list of the salaries paid is not published. They amount to about \$10,000. For the year 1902-3 \$2,224.86 was allowed for the laboratory expenses of the anatomical department and \$1,221.06 for those of the department of histology. With the exception of the janitor of the anatomical department no trained technicians are employed. The total yearly expenditure for the laboratories is somewhat less than \$15,000.

At the medical school of the *University of California* in the anatomical department there are a professor, an assistant professor, an instructor and four student assistants. The salaries of the instructional force amount to \$6,650 and \$2,500 is allowed for laboratory expenses. A skilled technician and a special janitor are employed the salaries of whom amount to \$1,300. The total running expenses amount to about \$10,500. For these data I am indebted to Professor Flint. President Wheeler kindly permitted their publication.

In the medical departments of those *State Universities* in which the most scientific work in anatomy is done the total yearly expenditures amount to between \$10,000 and \$15,000.

On comparing the table of the appropriations allotted to the anatomical laboratories of the most liberally treated American institutions with the corresponding figures given in note 10 for the German institutions it may be seen that in general the allotments in America are less. As to salaries it is probable that the German professors of anatomy are better paid than the American, while the American instructors and associates in the better institutions are better paid than the German dozenten.

(d) *Salaries.*

For 502 "ordenliche Professoren" in the Prussian Universities for the year 1900 the average income from salaries and fees was 11,735 M. Of these thirty had less than 6,000 M., seven between 30,000 and 40,000 M. and three over 40,000 M. (Die Universitäten im deutschen Reich, W. Lexis, 1904.) The professors of anatomy are among those who receive the highest income. One German professor is said to receive over \$10,000 a year from his courses in anatomy. In America the highest salary paid to a professor of anatomy is, I believe, \$7,500. There are three men who receive over \$5,000 and about the same number who receive \$4,000 to \$5,000, perhaps six who receive \$3,000 and as many who receive between \$2,000 and \$3,000. Several others receive \$2,000 or less. The great majority receive small salaries and depend on the practice of medicine for a living. The highest salaries are paid in endowed institutions. Assistant and associate professors in the richer endowed institutions receive from \$1,500 to \$2,500 and in the more liberal State institutions from \$1,000 to \$2,000 according to length of service. Instructors and associates receive as a rule from \$800 to \$1,500 when they devote all their time to teaching and research. Assistants seldom receive more than \$600. In America the professors and instructors in the medical schools who devote all their time to administration, teaching and research are paid about the same salaries which are paid to those holding corresponding positions in other departments of the universities. Their income is very much less than the more successful men who practice medicine.

(e) *Buildings.*

In respect to laboratories the anatomical departments of the German universities have as a rule a decided advantage over the American. The Harvard Medical School will soon have a splendid building especially designed for the subject. Associated with the University of

Pennsylvania is the Wistar Institute, a fine building designed for the beautiful Wistar anatomical museum and for research, but the building can not be used for undergraduate teaching. In the University laboratories the quarters devoted to human dissection have been inadequate. It is to be hoped that the immense building recently built there for laboratories for the medical department will now permit much more adequate quarters to be arranged for the student work in anatomy. At the Johns Hopkins University an unpretentious but convenient building is devoted to the anatomical department. (See F. Mall, *Bull. Johns Hopkins Hospital*, 1896.) The University of Chicago has a special building for anatomy. At Columbia University, Cornell University, the University of Michigan, Syracuse University, the University of California and the University of Missouri quarters designed especially for scientific anatomy have been placed in large laboratories devoted to the medical sciences. At the Universities of Iowa and Minnesota there are special buildings for human anatomy while histology and embryology are quartered in another building devoted to the medical sciences. In some other institutions more or less commodious quarters are given to gross and microscopic anatomy but in general anatomy in the American medical schools is far from being adequately housed. In the better institutions from 12,000 to 50,000 square feet of floor space are given up to the anatomical laboratories.

Professor Flint (*Bull. Johns Hopkins Hospital*, Feb. 1905, p. 33) has described the alteration of an old fashioned dissecting-room into modern quarters for scientific anatomy as follows:

"The large dissecting-room was provided with roof light, a tarred floor and rough brick walls. In the conversion of this space to more modern dissecting-rooms several points concerning anatomy in this country had to be born in mind. In the first place anatomical material was often poorly preserved and frequently scant in quantity; in the second, by tradition, students who crossed the threshold of a dissecting-room assumed at times that they were absolved from all standards of good conduct. Hats were worn; students dressed in outlandish costumes. Smoking was generally permitted, and boisterous conduct accompanied by the throwing of material, were not infrequent occurrences. To break this tradition and to obtain in a measure the morale and seriousness characteristic of the students in other departments of the university, we profited by the experience of Professor Mall of the Johns Hopkins University, who, in the construction of his laboratory, went on the assumption that students should be divided into small groups and should be provided with dissecting-rooms, which resemble a modern laboratory more than they do a stable. Accord-

ingly, the large dissecting-room was re-covered with a new floor, and was cut up into a series of small rooms, each with a capacity of from 1 to 4 tables, thus segregating small groups of students. In this way fewer distractions occur and one obviates the inevitable noise that occurs when large bodies of even well behaved students are quartered in the same laboratory. The rooms, moreover, were fitted with especial care to make them clean, neat, and attractive, hoping in this way to obtain the effect of a pleasant environment upon the work of the students during the period of dissection. The large room was 35 by 100 feet, and was subdivided into eight small dissecting-rooms, a research room and a museum. The largest of these small dissecting-rooms is 20 by 21 feet, with a comfortable capacity of four tables and a maximum of six, while the smallest is $12\frac{1}{2}$ by 15 feet, and holds one dissecting table conveniently. The remainder are so arranged as to hold from one to three tables. The rooms are provided with heavy tables with zinc tops, draining toward the center into a bucket suspended beneath the table. Adjustable arm-rests and book-stands also form part of the equipment. As soon as the body is cut in parts, students are no longer forced to work together, and in consequence one or two small tables with book-stands are provided in each dissecting-room. There is a sink with running-water and a large drip-board to hold parts while they are being moistened, or for the study of the viscera. Each room has, besides, an articulated skeleton for convenient reference and a blackboard upon which schemata may be drawn and relations studied. During the period of dissection the student is held responsible for his material, which must be carefully wrapped in cheese-cloth at the close of each laboratory period. These wrappings are moistened in a solution of carbonic acid, glycerine and water, made according to the following formula:

Water	1000cc.
Glycerine	30cc.
Carbonic acid	20cc.

"This procedure prevents desiccation and, at the same time, acts to a certain extent as a preservative."

In many of the leading institutions anatomical material is preserved in cold storage plants. Recently improved methods of embalming have, however, rendered these unnecessary except where large numbers of bodies must be cared for.

(f) Length of Courses.

The proportional amount of time devoted to human gross anatomy, histology and embryology varies greatly in different institutions. In 41 colleges the total amount of scheduled time devoted to medical studies during the four years' course averaged 4095 hours in 1902-3, the total amount of time devoted to human anatomy 549, and to histology and embryology 219. The standard proposed to the American Medical Association by the committee appointed to study the subject is 3600 hours for the course, 500 hours for anatomy and 200 hours for histology and embryology. The anatomical studies therefore constitute about a fifth of the medical curriculum proposed for American schools. (See Jrl. Am. Med. Assn., Aug. 15, 1903; and N. Y. Med. Jrl., July, 1904.)

23, (p. 99). CONTRIBUTIONS FROM PHYSIOLOGICAL AND
PATHOLOGICAL LABORATORIES.

Among the important contributions to anatomy made in this country from physiological laboratories may be mentioned the work of Howell on the blood, of Howell and Huber on the regeneration of nerves, and the extensive studies of Loeb and his pupils in experimental morphology. From the pathological laboratories the work of F. P. Mall on reticulum and on the blood vessels of the stomach, of Berkley on nerve endings in various tissues, of Mallery on stains and on the connective tissues, of Adolph Meyer on nerve cells, of E. L. Opie and R. M. Pearce on the pancreas, W. G. MacCallum on the lymphatics, and Warthin on the hæmolymp glands may especially be mentioned. A list of the numerous publications by clinicians on anatomical subjects would be too long for citation here. The work of Osler on the blood-plates, of Williams on the female reproductive organs, of Clark on the ovary and corpus luteum, of H. Cushing and Allen Starr on the nervous system, may, however, be mentioned.

24, (p. 99). DEVELOPMENT OF BIOLOGY IN AMERICA.

For the history of the development of the biological sciences in this country see:

A. S. Packard: "A Century's Progress in American Zoology." American Naturalist, Vol. 10, 1876.

G. Brown Goode: "Beginnings of American Science," Proceedings Biological Society, Washington, III, 1884-6, and IV, 1886-8.

J. P. Campbell: "Biological Teaching in the Colleges of the United States," U. S. Bureau of Education, Circular of Information, No. 9, 1891.

The letters of L. Agassiz ("L. Agassiz, his life and correspondence,") edited by his wife, throw interesting light on zoology in America at the period when Agassiz arrived here and during his life in this country.

25, (p. 100). JEFFRIES WYMAN AND THE HERSEY
PROFESSORSHIP.

In 1847 the Hersey professorship of anatomy was transferred from the Harvard Medical School in Boston to the newly established Lawrence Scientific School at Cambridge. O. W. Holmes was appointed to the newly established Parkman professorship of anatomy and physiology in the Medical School. At Cambridge Wyman had small classes in comparative, including human anatomy, and produced much scientific work of sterling value. Wyman died in 1874. Asa Gray delivered an interesting and sympathetic memorial address before the Boston Society of Natural History. (Vide Gray's Collected Works, and the Proceedings of the Boston Society of Natural History, Oct. 7, 1874.)

The Hersey professorship of anatomy was established from the bequest of Ezekiel Hersey of Hingham who died in 1770 leaving 1000 pounds and of his widow who left a like sum to be applied to the support of a professor of anatomy and surgery at Harvard. (Thatcher, Medical Biographies, 1828.) Dr. Abram Henry and Dr. John Cumming also each gave 500 pounds for the same purpose. This was the first endowed professorship of anatomy in America. Seldom has money been left to better purpose. John Warren, John Collins Warren, J. Wyman and E. L. Mark, who have successively held the chair have been among the foremost in the development of the anatomical sciences in America. The Parkman professorship of Anatomy was established at the Harvard Medical School in 1847 in honor of George Parkman who gave a large tract of land to the school. Recently James Stillman has given \$100,000 for the establishment of a professorship of comparative anatomy at the Medical School. It would be well were similar endowed professorships in anatomy established in connection with other universities.

26, (p. 100). AGASSIZ.

The brilliant American career of Agassiz, who became professor of zoology in the Lawrence Scientific School at its establishment in 1847, is too well known to be treated here at length. He awakened great popular interest in biology in a country where there had previously been but little and did more perhaps than any other one individual to sow the seeds of the fruitful zoology which has grown up since his death in 1873. He introduced the study of comparative embryology into this country and excited fresh interest in paleontology and the broader relationship existing between living organisms. Agassiz's interest however, was rather in structure as a basis of systematic classification than in the intrinsic structure of organisms or in structure in relation to function. In the *American Naturalist* for 1898 may be found a list of the chief pupils of Agassiz.

27, (p. 100). CONTRIBUTIONS FROM THE ZOOLOGICAL LABORATORY OF HARVARD COLLEGE UNDER THE CHARGE OF E. L. MARK.

Among the contributors to anatomy may be mentioned:

Howard Ayres; M. A. Bigelow, adjunct professor of biology, Teachers College, Columbia; R. P. Bigelow, instructor in biology, Massachusetts Institute of Technology; Mary A. Bowers, instructor in zoology, Wellesley College, Wellesley, Mass.; W. E. Castle, assistant professor of zoology, Harvard University; C. B. Davenport, director Carnegie Laboratory, Cold Spring Harbor, Long Island, N. Y.; Gertrude C. Davenport; C. R. Eastman, assistant in vertebrate paleontology, Museum of Comparative Zoology, Harvard University; C. H. Eigenmann, professor of zoology, University of Indiana; H. H. Field, director of concilium bibliographicum, Zurich, Switzerland; R. W. Hall, instructor in zoology and biology, Lehigh University, South Bethlehem, Pa.; J. I. Hamaker, professor of geology and biology, Trinity College, Durham, N. C.; Ida H. Hyde, associate professor of physiology, University of Kansas, Lawrence, Kas.; H. S. Jennings, associate professor of zoology, University of Pennsylvania; C. A. Kofoid, associate professor of histology and embryology, University of California; T. G. Lee, professor of histology and embryology, University of Minnesota; F. T. Lewis, instructor in embryology and histology, Harvard Medical School; W. A. Locy, professor of zoology, Northwestern University; W. J. Moenkhaus, assistant professor of physiology, Indiana Univer-

sity; H. V. Neal, professor of biology, Knox College, Galesburg, Ill.; Margaret L. Nickerson, instructor in histology and embryology, University of Minnesota; W. S. Nickerson, associate professor of histology and embryology, University of Minnesota; Herbert Osborn, professor of zoology and entomology, Ohio State University; G. H. Parker, associate professor of zoology, Harvard University; W. Patten, professor of zoology, Dartmouth College; Julia B. Platt; C. W. Prentiss, instructor in biology, Western Reserve University; H. W. Rand, instructor in zoology, Harvard University; J. E. Reighard, professor of zoology, University of Michigan; W. E. Ritter, professor of zoology, University of California; Porter E. Sargent, Cambridge, Mass.; F. Smith, University of Illinois; R. M. Strong, instructor in zoology, University of Chicago; W. L. Tower, associate in embryology, University of Chicago; F. C. Waite, assistant professor of histology and embryology, Western Reserve University; H. B. Ward, professor of zoology, University of Nebraska; A. W. Weyse, instructor in zoology, Massachusetts Institute of Technology; C. O. Whitman, professor of zoology, University of Chicago; W. A. Willard, adjunct professor of zoology, University of Nebraska; S. R. Williams, professor of biology, Miami University, Oxford, Ohio; W. M. Woodward, keeper of the Museum of Comparative Zoology, Cambridge, Mass.

28. (p. 100). SCHOOLS OF ANATOMY AT BROWN AND CORNELL.

Under the stimulus of Professor Packard, Brown built up a strong productive department of zoology and anatomy. In 1890 H. C. Bumpus was added to the staff and from 1891-1902 was professor of comparative anatomy. In 1902 Professor Bumpus became director of the American Museum of natural history, New York. At present A. D. Mead is professor of comparative anatomy, F. P. Gorham is associate professor of biology, and F. T. Fulton instructor in pathology and histology. Human anatomy has been taught there since 1902.

An appreciative account of Professor Packard's life work may be found in *Science*. March 17, 1905.

The development of anatomy at Cornell under Professor Wilder has been treated of in note 22.

29. (p. 100). YALE.

At Yale, B. Silliman, professor of chemistry, mineralogy and geology, from 1802 to 1864, though no anatomist, did much to arouse in-

terest in natural science. J. D. Dana, professor of geology and mineralogy from 1850 to 1895, was a good zoologist, as well as a great geologist. A. E. Verrill has been professor of zoology since 1864, and S. I. Smith professor of comparative anatomy since 1875. O. C. Marsh, who was appointed professor of paleontology in 1866, made many contributions to this subject.

30, (p. 100). PRINCETON.

At Princeton an active scientific atmosphere was introduced by Arnold Guyot, Agassiz's friend, professor of geology from 1854 to 1884. This was furthered by the establishment of the John C. Green School of Science in 1873. Professors Scott, Osborn and McClure have done much there to develop comparative anatomy.

Among those who have contributed to anatomy at Princeton may be mentioned G. Macloskie, professor of biology since 1882; W. B. Scott, professor of geology since 1882; H. F. Osborn, professor of comparative anatomy from 1882 to 1892; C. T. W. McClure, instructor and professor of comparative anatomy since 1893; W. M. Rankin, instructor and professor of invertebrate zoology since 1892; and U. Dahlgren, instructor in histology since 1896. Professor Scott has established an unusually good paleontological museum, and Professor McClure one of the best museums of comparative anatomy in the country.

31, (p. 100). PENNSYLVANIA.

Philadelphia since the time of Franklin has been an active center for research. The University, however, did little for scientific anatomy, in spite of the activities of men like Horner, Leidy and Harrison Allen, until 1873, when a laboratory for comparative anatomy was established. (See "Benj. Franklin and the Univ. of Penn.," F. N. Thorpe, U. S. Bureau of Ed., Circ. of Inf., 1892, No. 2.) In 1884, owing to the generosity of H. Jayne and the support of the provost, W. Pepper, the School of Biology was established. In 1889 this became the department of Biology. Under the leadership of such men as Leidy, Cope, Ryder, and Conklin, the work done here has gone far to further the advance of anatomy, as well as other aspects of biology in this country.

The professors in the biological department at Pennsylvania have been, in comparative anatomy, A. J. Parker, from 1880 to 1890, H. Allen, from 1891 to 1895, E. D. Cope, 1886-1897; in invertebrate morphology, B. Sharp, from 1884 to 1886; in physiology, N. G. Randolph, from 1883 to 1886, H. A. Hare, from 1887 to 1890, E. Reichert, since

1890; in biology, H. Jayne, from 1883 to 1884, C. S. Dolle, from 1885 to 1888, M. J. Greenman, 1887; mammalian anatomy, C. M. Burk, 1887-1897, E. A. Kelly, from 1887 to 1889; zoology, E. G. Conklin, since 1899; comparative embryology, J. A. Ryder, from 1886 to 1895, E. G. Conklin, from 1895 to 1899. H. S. Jennings is assistant professor of zoology and J. P. Moore and P. P. Calvert are instructors in zoology. T. H. Montgomery, now professor of zoology at the University of Texas, was assistant professor of zoology, from 1900 to 1903. Among others who have made contributions from the laboratory may be mentioned: H. Heath, H. Crawley, J. R. Murlin, D. B. Casteel, E. F. Phillips, J. L. McClendon, Louise Nichols, Caroline Thompson, Louise B. Wallace, J. A. Nelson, R. C. Schmidt and H. Fox.

32. (p. 100). THE JOHNS HOPKINS.

In 1876 the Johns Hopkins University was opened with H. Newell Martin as professor of biology and W. K. Brooks as fellow. While Martin developed an active graduate school for the training of vertebrate physiologists, Brooks paid particular attention to the biology of invertebrates. He organized the Chesapeake Zoological Laboratory, which was established for several successive summers at different places along the Atlantic coast and did much to further the study of the anatomy and development of the marine fauna of the region.

Among the biologists who studied at the Johns Hopkins University may be mentioned J. P. MacMurrich, professor of zoology, Haverford, from 1886 to 1889, professor of anatomy at Michigan since 1893; S. F. Clarke, professor of zoology at Williams since 1881; W. T. Sedgwich, professor of biology at the Massachusetts Institute of Technology since 1884; E. B. Wilson, professor of zoology at Bryn Mawr from 1885 to 1891, and at Columbia since 1891; C. O. Whitman, director Allis Lake Laboratory, from 1886 to 1889, and professor at Chicago since 1892; H. H. Donaldson, professor of neurology at Chicago since 1892; H. F. Nachtrieb, professor of zoology at Minnesota since 1885; H. L. Osborn, professor at Purdue from 1884 to 1887, professor of biology and geology at Hamlin University, St. Paul; F. H. Herrich, professor of biology at Western Reserve University since 1881; A. B. Macallum, professor of physiology at Toronto since 1886; H. V. Wilson, professor of biology at the University of North Carolina since 1888; T. H. Morgan, professor of biology, Bryn Mawr from 1891 to 1904, professor at Columbia, 1904; E. G. Conklin, professor of zoology, Northwestern University from 1891 to 1895, professor of zoology, University of Pennsylvania since

1895; R. G. Harrison, associate professor of anatomy, Johns Hopkins University since 1895; G. Lefevre, professor of zoology, University of Missouri since 1898; C. P. Sigerfoos, assistant professor of zoology, University of Minnesota since 1897; G. A. Drew, professor of biology, University of Maine since 1900; C. W. Greene, professor of physiology, University of Missouri since 1900; C. Grave, associate in zoology, Johns Hopkins University; J. E. Duerden; A. M. Reese, associate professor of histology, Syracuse University; W. C. Curtis, assistant professor of zoology, University of Missouri and G. L. Houser, professor of animal morphology, Iowa University.

33, (p. 100). RECENT DEVELOPMENT OF BIOLOGY.

"In all of the 400 colleges and universities, with a dozen conspicuous exceptions, the instruction in the biological sciences is little more than a farce. The teachers of biology are mostly men without biological training, men whose ideas and methods are those of a generation ago, and who have no more idea of modern science and scientific thought than have the poorest pupils who are unfortunate enough to come under them"; wrote the editor of the *American Naturalist* in 1887.

In 1891 out of the 111 colleges and universities in but 41 were the biological departments in the hands of men devoted to teaching that subject only; there were but five laboratories built especially for biology, only five or six institutions where advanced experimental work could be performed and only three or four in which provision was made for the study of vegetable physiology. (See J. B. Campbell, U. S. Bureau of Education, Circular of Information, 1891.)

Early in the nineties a notable impetus to the advance of biology was given by the establishment of several liberally endowed universities the direction of which fell into the hands of men in sympathy with scientific research.

At *Columbia* in 1890 N. L. Britton was appointed professor of botany, and in 1896, L. M. Underwood. In 1891 H. F. Osborn and E. B. Wilson were appointed professors of zoology. From 1811 until 1890 *Columbia* had no professor of natural history, botany or zoology. Under the leadership of Professors Wilson and Osborn, Britton and Underwood, *Columbia* has developed into one of the strongest departments of biology in the world, and from there many important contributions to anatomy have been made. Bashford Dean was made adjunct professor of zoology in 1896, H. E. Crampton, G. N. Calkins,

M. A. Bigelow in 1903. In 1904 T. H. Morgan was made professor of experimental zoology. Among others in the collegiate department who have contributed more especially to anatomy may be mentioned J. H. McGregor, instructor in zoology, and O. S. Strong, tutor in comparative neurology. In addition to the work of these men important contributions have been made by B. A. Bensley, L. I. Dublin, B. B. Griffin, N. R. Harrington, C. J. Herrick, professor of biology, Denison University, Granville, Ohio, W. E. Kellicott, R. S. Lull, A. P. Mathews, assistant professor of physiological chemistry, University of Chicago, F. B. Sumner, instructor in natural history, College of the City of New York, W. S. Sutton, J. C. Toner, N. Yatsu, and Charles Zeleny, instructor in zoology, the University of Indiana.

At *Clark University*, organized at Worcester in 1889, the President, G. Stanley Hall, got together a remarkable number of productive biologists, among whom may be mentioned G. Baur, F. Boas, H. C. Bumpus, H. H. Donaldson, C. L. Edwards, A. C. Eycleshymer, C. F. Hodge, E. O. Jordan, F. R. Lillie, W. P. Lombard, F. P. Mall, W. S. Miller and W. M. Wheeler. After three years of scientific activity the laboratory was disorganized by the departure of the greater part of the men mentioned to the university newly organized at Chicago. Since 1892 Chicago has had one of the most productive biological departments in the country.

The original staff at the *University of Chicago* consisted of C. O. Whitman, professor of biology and animal morphology; F. P. Mall, professor of anatomy; H. H. Donaldson, professor of neurology; J. Loeb, assistant professor of physiology; G. Baur, assistant professor of paleontology; W. M. Wheeler, instructor in biology; A. D. Mead, fellow in biology; A. C. Eycleshymer, assistant in animal morphology; and F. R. Lillie, fellow in morphology. Mall became professor of anatomy at the Johns Hopkins University; Wheeler, professor of zoology at the University of Texas and later curator of invertebrate zoology at the American Museum, New York; A. D. Mead, associate professor of embryology and neurology, then professor of comparative anatomy at Brown; A. C. Eycleshymer, professor of anatomy at the University of St. Louis. C. B. Davenport became assistant professor of zoology at Chicago in 1899. In 1904 he assumed charge of the Carnegie laboratory at Cold Spring Harbor. At present the work in anatomy in the laboratory is done under the direction of Professor Whitman and of F. R. Lillie, associate professor of embryology. Among those who have worked on anatomical problems in the zoological department at Chicago in addition to those named above may be mentioned B. M. Allen, instructor in anatomy, the University of Wisconsin; W. J. Baum-

garten, instructor in zoology, the University of Kansas; C. M. Child, instructor in zoology, the University of Chicago; C. M. Clapp, professor of zoology, Mt. Holyoke College, S. Hadley, Mass.; Agnes M. Claypole; E. R. Downing, professor of biology, Michigan Northern State Normal School; M. F. Guyer, professor of zoology, University of Cincinnati; E. H. Harper, instructor in zoology, Northwestern University, Evanston; O. P. Hay, curator, American Museum of Natural History; S. J. Holmes, instructor in zoology, University of Michigan; G. W. Hunter, Jr.; E. Kirk, assistant in anatomy, Chicago; Henry Lane; R. S. Lillie, instructor in physiology, University of Nebraska; W. A. Locy, professor of zoology, Northwestern University; W. J. Moenkhaus, assistant professor of physiology, the University of Indiana; J. Scott and R. M. Strong, instructors in zoology, and L. T. Tower, instructor in embryology, the University of Chicago; A. L. Treadwell, professor of biology, Vassar College, Poughkeepsie, N. Y.; S. Watase, professor of cellular biology, the University of Tokio; W. Zelleny, instructor in zoology, the University of Indiana. (See University of Chicago Decennial Publications, First Series, Vol. I, President's Report.)

Although the establishment of active, scientifically productive biological departments at Columbia and the University of Chicago mark the chief recent events in the progress of anatomical research, from the biological standpoint, there has been an impulse in the same direction in many other colleges and universities. In addition to the zoological departments of these two institutions and the leading departments in the older institutions such as those of Harvard, the Johns Hopkins, Pennsylvania, Princeton, Cornell and Brown, there may be mentioned the departments at Alma College, Michigan, under B. N. Harper; Bryn Mawr, successively under E. B. Wilson, and T. H. Morgan; California under W. E. Ritter; Dartmouth under W. Patten; Cincinnati under M. F. Guyer; Denison University, Granville, Ohio, under C. H. and C. J. Herrick; the University of Indiana under C. H. Eigenmann and W. J. Moenkhaus; the University of Iowa under G. L. Houser; the University of Kansas under S. W. Williston, Ida H. Hyde and C. E. McClung; Knox College, Galesburg, Ill., under H. V. Neal; Leland Stanford, Jr., University, under O. P. Jenkins and F. M. McFarland; the University of Maine, Orono, under G. Drew; the University of Michigan under J. E. Reighart and H. O. Jennings; the University of Minnesota under H. F. Nachtrieb and G. E. Sigerfoos; the University of Missouri under G. Lefevre and W. C. Curtis; Mt. Holyoke under C. M. Clapp; Nebraska successively under J. S. Kingsley and H. B. Ward; the University of North Carolina under H. V. Wilson; Northwestern University under W. A. Locy; Ohio Wesleyan, Delaware, Ohio,

under E. L. Rice; Smith College, Northampton, under H. H. Wilder; Syracuse University under C. W. Hargitt; Texas successively under W. M. Wheeler and T. H. Montgomery; Trinity College, Hartford, under C. L. Edwards; Tufts College, under J. S. Kingsley; Vassar College, Poughkeepsie, under A. L. Treadwell; the University of West Virginia, under J. B. Johnston; Western Reserve University, Cleveland, Ohio, under F. H. Herrick; Williams College under S. F. Clarke, J. J. Peck and J. L. Kellogg; the University of Wisconsin under E. A. Birge, W. S. Marshall and W. S. Miller; and the Woman's College, Baltimore, under M. M. Metcalf and F. Peebles. In a number of other institutions there has been considerable activity in lines of research other than the morphological. In perhaps 20 per cent of the colleges and universities of the country some scientific investigation in biology is carried on.

In almost all of these institutions, however, there is still far too much routine teaching done by the members of the staff. Agassiz prided himself on teaching men to observe. His educational children and grandchildren spend too much time in telling pupils what to know. Research is carried on chiefly during vacations and too often without intelligent support from those in whose hands the direction of the institution lies. Little training in investigation can under these circumstances be given to others, and what scientific work is done is mainly by instructors who have elsewhere received their training. There are some exceptions. Among these are Bryn Mawr College, where, under E. B. Wilson and then under T. H. Morgan, there was developed a laboratory wonderfully productive in the field of experimental morphology, the state universities of Michigan, Nebraska, Indiana and Wisconsin, and Denison University, Granville, Ohio.

The study of *vegetable anatomy* was taken up in a scientific spirit later than animal morphology and has received less extensive study. Among universities in the biological departments of which it has received special attention may be mentioned Harvard, under the direction of W. G. Farlow, and R. Thaxter, Columbia under L. M. Underwood, Nebraska under C. E. Bessey, Leland Stanford under D. H. Campbell, the University of California under W. A. Setchell, the Johns Hopkins under D. S. Johnson, the University of Indiana under S. M. Mottier, and the University of Wisconsin under R. A. Harper.

Biological laboratories well adapted for work, though often overcrowded, may be found at the following, among other institutions: Bryn Mawr, Brown, Cornell, Harvard, the Johns Hopkins University, Leland Stanford, Michigan, Minnesota, Pennsylvania, Princeton, Trinity College, Hartford, Vassar College, Western Reserve University, and

Williams. In most institutions the biological laboratories still occupy ill adapted quarters in some building devoted to many other purposes.

34, (p. 100). RELATIONS OF UNIVERSITY BIOLOGICAL DEPARTMENTS TO MEDICAL SCHOOLS.

At the time of the establishment of a graded curriculum in the medical schools the better colleges offered good practical laboratory courses in general biology (see Note 18). Students who had taken the work were found often to succeed better in medicine than those who had not. In many medical schools they were given advanced standing. With the increase of standards of admission to the better schools a certain amount of preliminary training in biology was required. In addition to this required amount of work many universities, like Wisconsin, offered in their biological departments opportunity for some of the work covered by the first two years of the medical curriculum. At Harvard in the fifties, at Cornell in the seventies, some opportunity for the dissection of human bodies was offered. In 1890 the University of North Carolina offered the first year of the medical curriculum in its collegiate department and a few years later the first two years of a four years course, the last two years being given at Raleigh. The University of Kansas offered in 1894-5 a course covering the first years work of the medical curriculum of a good medical school and in 1898-99 the work of the first two years was offered. In 1898 Cornell offered at Ithaca, N. Y., the full first two years of a medical curriculum. In its medical department at New York a complete four year course is offered. In 1900 the University of Chicago entered into an agreement with the Rush Medical College whereby the courses in biological sciences, in chemistry and in physics, requisite for a medical training, were to be given at the University, while the clinical branches were to be taught as heretofore at the Medical College. In 1902 the University of Nebraska adopted a policy similar to that of Cornell, mentioned above. In 1902 the University of West Virginia, and in 1903 the Universities of Indiana and Mississippi offered work covering the first two years of a medical curriculum. Brown University, Providence, Rhode Island, likewise offers much of the work commonly covered in this curriculum, although no attempt is there made to forestall the work of the medical school.

35, (p. 101). SEA SIDE AND LAKE LABORATORIES.

The establishment of laboratories at the sea side and lake shore for the purpose of furnishing facilities for biological study and investigation, either during the summer or throughout the year, began when John Anderson presented Agassiz with Penikese Island and \$50,000 as an endowment for a laboratory. At Agassiz's death in 1873 this laboratory was discontinued. Alexander Agassiz established a private laboratory at Newport, R. I., soon afterwards, and has extended its facilities to a number of workers. In 1881 the Boston Society of Natural History had a laboratory at Annisquam, Mass. From 1878 to 1891 the Chesapeake Zoological Laboratory of the Johns Hopkins University was established each summer at various places along the Atlantic coast under the direction of Professor Brooks. From 1886 to 1889 E. P. Allis supported a private Lake Laboratory at Milwaukee under the direction of Professor C. O. Whitman, and later under Howard Ayres.

In 1888 the Marine Biological Laboratory was established at Woods Hole, Mass., and C. O. Whitman was made director. About thirty colleges, universities and medical schools, several academies and societies, and the Carnegie Institution have contributed to the support of the laboratory by maintaining there "tables" for scientific workers. The members of the corporation are elected chiefly from those who make or have made use of the facilities of the laboratory for scientific study. They in turn elect a board of trustees, of whom there are at present twenty-six. Of these, sixteen are professors in the biological sciences in various colleges and universities, four are biologists not connected with educational institutions, and six are business men interested in the success of the laboratory. In addition there are three ex-officio members, C. O. Whitman, director of the laboratory, F. R. Lillie, assistant director of the laboratory, and A. W. Wilcox, clerk of the corporation.

Instruction and investigation are carried on at the laboratory, during the summer months, in zoology, embryology, physiology and botany. No factor has been more potent in arousing interest in biological investigation in this country. To name those who have worked at this laboratory for greater or less periods of time and have made important contributions in the field of anatomy, as well as in other fields of biological study, would be to name the great majority of the leading biologists of the country. In publications of the laboratory lists of the investigators and their contributions may be found.

In 1889 a biological laboratory was established at Cold Spring Harbor by the Brooklyn Institute of Arts and Sciences. This laboratory has been in charge successively of B. Dean, H. W. Conn, and C. B. Davenport. In 1891 the University of Pennsylvania maintained a laboratory at Sea Isle City. More recently J. S. Kingsley has established a summer laboratory near Portland, Maine, and the University of Minnesota, the University of California and Leland Stanford have established marine laboratories on the Pacific coast. The University of Nebraska, since 1899, has maintained a lake laboratory during the summer, and other institutions have similar laboratories.

Harvard University, New York University and the Bermuda Natural History Society for several seasons have offered American biologists laboratory facilities at the Island of Bermuda.

The United States Fish Commission under S. Baird offered in the seventies opportunity for scientific investigation at the Fish Commission Station at Woods Hole. It now maintains laboratories open to scientific workers at Woods Hole, Mass., Beaufort, North Carolina, and at Put-in-Bay, Ohio, on Lake Erie. Lately the Carnegie Institution has established an institution for biological research at Cold Spring Harbor. C. B. Davenport has been made director.

In many respects these various laboratories constitute our truest university biological departments. There is such a tendency to force a man to consume all of his time in teaching and routine administration in the majority of American colleges and universities that the chief part of the biological research done in this country is done in the summer and a large part at the leading marine and lake laboratories. The leading men who go serve to furnish ideas to others who want to work. The tables maintained by the Smithsonian and other institutions at the biological station at Naples, in Italy, have likewise proved a great aid to American biologists. All who have had the privilege of being there feel the deepest gratitude to Professor Dohrn and the members of his staff for their many courtesies and kindnesses.

36. (p. 101). MUSEUMS.

The American Museum of Natural History at New York under the charge of Professor Bumpus, the Field Columbian Museum at Chicago, the National Museum at Washington, the Boston Society of Natural History, the Academy of Science, the Wistar Institute of Anatomy at Philadelphia, the Agassiz Museum at Cambridge, and the Army Medical Museum at Washington should here more especially be mentioned.

Under the active leadership of Dr. M. J. Greenman, recently appointed director of the Wistar Institute, and with the hearty co-operation of General Wistar, its founder, and of the board of managers steps have been taken greatly to enlarge its scope.

"Ten of the leading American anatomists were invited to take part in a conference held at the institute on Tuesday and Wednesday, April 11 and 12, to consider with the management of the Wistar Institute the question of increasing the usefulness of the Wistar Institute to American anatomists by establishing relationship with the individual anatomists of the country, with the Association of American Anatomists, with the *American Journal of Anatomy* and with similar institutes abroad; and also by establishing an advisory board of anatomists of the Wistar Institute, with ten or more members, selected from the leading anatomists of the country.

The following anatomists were present at the conference:

Dr. Lewellys F. Barker, professor of anatomy, University of Chicago, Chicago, Ills.

Dr. Edwin G. Conklin, professor of zoology, University of Pennsylvania, Philadelphia, Pa.

Dr. Henry H. Donaldson, professor of neurology, University of Chicago, Chicago, Ills.

Mr. Simon H. Gage, professor of embryology, Cornell University, Ithaca, N. Y.

Dr. G. Carl Huber, professor of embryology and histology, University of Michigan, Ann Arbor, Mich.

Dr. George S. Huntington, professor of anatomy, Columbia University, New York City.

Dr. Franklin P. Mall, professor of anatomy, Johns Hopkins University, Baltimore, Md.

Dr. J. Playfair McMurrich, professor of anatomy, University of Michigan, Ann Arbor, Mich.

Dr. Charles S. Minot, professor of embryology, Harvard Medical School, Boston, Mass.

Dr. George S. Piersol, professor of anatomy, University of Pennsylvania, Philadelphia, Pa."

At this meeting the following recommendations were adopted:

"(1) The principal object of the institute to be research and under these headings: (a) a chief of investigation, (b) research assistants or assistantships and men who shall divide their services between the museum proper and research, (c) technical assistants. (2) Research and materials: (a) research shall be in the field of neurology, (b) comparative anatomy and embryology. (3) Relations: (a) committee

recommends that the subvention of the *Journal of Anatomy* be granted, (b) committee be appointed to consider relations of the Wistar Institute to American anatomists, (c) the Wistar Institute to apply to the Association of American Anatomists for cooperation. (4) That an advisory board of ten be appointed for general purposes: (a) to form a sub-committee on neurology as well as other sub-committees that may be needed, (b) to establish relations with the committee of the International Association of Academies for Brain Investigation and with other committees for collective investigation, (c) the committee recommends that the board bear in mind that while the general trend of work above outlined is recommended there is no intention to advise limitation of the functions of the institute to it exclusively.

"The advisory board proceeded to appoint the following committees: on neurology and the establishment of relations with the International Association of Academies, Dr. L. F. Barker, Dr. H. H. Donaldson, Dr. F. P. Mall, Dr. J. P. McMurrich, Dr. C. S. Minot (this committee to elect its own chairman); on relations of the Wistar Institute to American Anatomists, Professor S. H. Gage, chairman, Dr. Geo. A. Piersol, Dr. G. Carl Huber; on comparative anatomy and embryology, Dr. Geo. S. Huntington, chairman, Dr. E. G. Conklin, Dr. F. P. Mall." (*Science*, May 5, 1905.)

The members of the conference have been appointed a permanent advisory board of the institute.

37 (p. 101). SOCIETIES.

The oldest of the American Scientific Societies, the American Philosophical Society, which originated from a society founded in 1743, the American Academy of Arts and Sciences, founded in 1780, the various state and municipal Academies of Science, and the medical societies of the country long afforded some means of verbal communication of anatomical discoveries and for their publication.

The great popularizing society, the *American Association for the Advancement of Science*, founded in 1848, has performed a similar service. Among its presidents two morphologists are to be found, Jeffries Wyman, 1857, C. S. Minot, 1901, and three paleontologists, Louis Agassiz, 1851, O. C. March, 1878, and E. D. Cope, 1896. At the twenty-fourth session of the society, in 1875, the association met in two sections, of which one was given up to "Natural History," with sub-sections in microscopy, anthropology, and entomology (1881). At the thirty-first session, in 1882, the society met in nine sections of which

one was devoted to "Biology," one to "Microscopy" (given up in 1885), and one to "Anthropology." Since 1892 the "Biological Section" has been divided into Zoological and Botanical Sections. In 1902 a section of physiology and experimental medicine was formed. There has never been a section devoted especially to anatomy, but numerous papers dealing with various aspects of organic structure have been presented before the various sections mentioned. Among those who have presided over the section "Biology" may be mentioned E. D. Cope, 1884, B. G. Wilder, 1885, C. S. Minot, 1890, and S. H. Gage, 1892. W. G. Farlow, who has done much to advance vegetable anatomy in this country, presided in 1887. In section "F," "Zoology," H. F. Osborn, 1893, A. S. Packard, 1898, S. H. Gage, 1899, C. B. Davenport, 1900, E. L. Mark, 1902 and 1904, and C. W. Hargitt, 1903, zoologists who have devoted much attention to morphological problems, were among those selected to preside. Among the presidents of the section "G," "Botany," there have been several who have devoted especial attention to the anatomy of plants, C. E. Bessey, 1893, L. M. Underwood, 1894, and W. G. Farlow, 1898. Of the presidents of section "H," "Anthropology," D. G. Brinton, 1887, Frank Baker, 1890, and W. H. Holmes, 1892, have all contributed toward physical anthropology.

In 1878 a growing popular interest led to the formation of the *American Microscopical Society*. Although some valuable papers have been presented before this society, there is comparatively little in its Transactions of interest to the professional anatomist.

In 1881 the Society of Naturalists of the Eastern United States was organized for the discussion of methods of investigation and instruction, laboratory technique and museum administration and other topics of interest to investigators and teachers of natural science. Membership was restricted to those who had done original work. For several years this society proved a valuable means of bringing together the leading biologists of the country once a year to discuss the various topics mentioned above. After the formation of the American Morphological Society in 1890 the Society of Naturalists finally became converted into an organization for the maintenance of a center at which numerous special societies devoted to various aspects of natural history might meet in conjunction. Among the special societies are the Association of American Anatomists, the American Morphological Society, the American Physiological Society, the American Psychological Association, the American Society of Zoologists, the Society of American Bacteriologists, the Geological Society of America, the Society for Plant Morphology and Physiology, the American Anthropological Association, the American Society of Vertebrate Paleontologists, etc. The

Society of Naturalists arranges railroad rates and holds an annual meeting and an annual dinner at which speeches devoted to some topics of the day important to biologists, are given by distinguished investigators. Since 1902 it has had Eastern and Central sections.

The increased interest in the anatomical sciences, which developed in this country during the last quarter of the nineteenth century, led in 1888 to the establishment of the *Association of American Anatomists*.

This association was formed at a meeting of the Congress of American Physicians and Surgeons at Washington, September, 1888. Among the organizers were Dr. Harrison Allen of the University of Pennsylvania; Dr. Frank Baker, Professor of Anatomy, Georgetown University; Dr. Augustus Bernays, Professor of Anatomy, the St. Louis College of Physicians and Surgeons; Dr. W. W. Gray, Microscopist, Army Medical Museum; Dr. Horace Jayne, Professor of Vertebrate Morphology, the University of Pennsylvania; Dr. D. S. Lamb, Professor of Anatomy, Medical Department, Howard University, Washington, D. C.; Mr. F. A. Lucas, Osteologist, U. S. National Museum; Dr. George McClellan, of Philadelphia; and Dr. J. Wortman, Anatomist, Army Medical Museum. The object of the society was and is "the advancement of the anatomical sciences." The first president was J. Leidy.

Among the more prominent of other early members may be mentioned E. P. Allis, H. Ayers, George Bauer, J. A. Blake, E. D. Cope, W. T. Councilman, T. Dwight, P. A. Fish, F. Baker, S. H. Gage, T. N. Gill, C. Heitzmann, C. J. Herrick, G. S. Huntington, W. W. Keen, G. T. Kemp, T. G. Lee, J. Leidy, C. S. Minot, J. P. McMurrich, O. C. Marsh, H. F. Osborn, G. A. Piersol, J. A. Ryder, W. B. Scott, F. J. Shepherd, R. W. Shufeldt, E. C. Spitzka, T. B. Stowell, B. G. Wilder, S. W. Williston, W. P. Wilson, and R. Ramsey Wright.

In 1891 there were 84 members. Of these 44 were professors and instructors in various medical schools, scarcely half a dozen of whom could properly be called scientific investigators. Ten were professors and instructors in zoology, all men of scientific attainments, five were scientists on the staff of the U. S. Museum, three were professors of geology and paleontology, two professors of botany, and the rest were variously interested in the study of the biological sciences.

In 1894 out of 300 professors and demonstrators of anatomy in the various medical schools of this country and Canada but 48 were members of the association. At the time of the last publication of a list of members of the association (1903), there were 150 members, of whom 101 were professors and instructors in medical schools. Of these about half have published scientific articles of merit. Hereafter scientific

work will be made a requirement for admission. Of the remaining 49, two are anthropologists, twelve zoologists, two botanists, twenty-five physicians and surgeons, one a pathologist, five physiologists, one a pharmacologist, and one is a maker of anatomical models. The medical departments of 42 out of 166 medical schools of the country are represented. In addition seven universities not having medical departments are represented, as well as the Field Columbian Museum, Army Medical Museum and the Philadelphia Commercial Museum.

The following table shows the geographical distribution of the members since the society was founded:

	1888.	1891.	1892.	1894.	1895.	1897.	1898.	1899.	1900.	1901.	1902.	1903
Pennsylvania...	23	19	21	18	17	14	15	9	9	9	10	15
New York	12	19	22	21	24	28	40	35	39	38	35	36
Dist. Columbia.	9	17	16	17	18	17	17	14	14	9	11	10
Massachusetts.	8	7	7	9	9	9	9	10	9	11	13	15
Canada.....	3	3	4	3	4	4	5	6	6	6	6	6
Illinois.....	3	4	5	3	2	4	4	4	8	16	19	18
Virginia.....	3	3	3	2	3	5	5	5	5	3	5	5
Connecticut...	2	3	2	5	5	5	5	4	3	4	4	4
California.....	2	1	1	1	1	1	1	1	1	3	4	4
Louisiana.....	2	2	2	2	2	2	2	2	3	2	2	2
Missouri.....	2	1	1	4	4	5	5	3	4	5	5	6
Colorado.....	1	1	1	1	1	1	1	1	1	0	1	1
Kansas.....	1	1	1	1	1	1	1	1	1	2	1	1
Maryland.....	1	1	1	1	1	1	3	4	8	8	9	12
Minnesota.....	1	1	2	1	1	1	1	1	1	1	2	2
Michigan.....	1	2	1	1	1	1	2	2	1	2	3	4
Nebraska.....	1	1	1	1	1	1	1	1	1	1	1	1
New Jersey.....	1	1	1	1	1	1	1	1	1	1	1	1
New Mexico.....	1	1	1	1	1	1	1	1	1	1	1	1
Ohio.....	1	2	2	4	6	5	5	5	5	4	4	4
Tennessee.....	1	1	1	1	1	1	1	1	1	1	1	1
Texas.....	1	1	1	2	1	3	3	2	1	1	2	3
Wisconsin.....	1	1	1	1	1	1	1	2	2	2	2	2
Maine.....	1	2	2	3	3	5	5	6	6	6	7	9
Iowa.....	1	1	1	1	1	1	1	1	1	1	1	1
Arizona.....	1	1	1	1	1	1	1	1	1	1	1	1
West Virginia..	0	1	1	1	1	1	1	1	1	1	1	1
South Carolina..	1	1	1	1	1	1	1	1	1	1	1	1
Oregon.....	1	1	1	1	1	1	1	1	1	1	1	1
New Hampshire..	1	1	1	1	1	1	1	1	1	1	1	1
Georgia.....	1	1	1	1	1	1	1	1	1	1	1	1
North Carolina..	1	1	1	1	1	1	1	1	1	1	1	1
Indiana.....	1	1	1	1	1	1	1	1	1	1	1	1

The presidents of the society have been, Dr. Joseph Leidy, 1888 to 1890; Dr. Harrison Allen, from 1891 to 1892; Dr. Thomas Dwight, from 1893 to 1894; Dr. Frank Baker, from 1895 to 1896; Dr. B. G. Wilder, from 1897 to 1899; Dr. George S. Huntington, from 1899 to 1903, and Dr. C. S. Minot, 1904.

Under the leadership of Professors Huntington, Huber, Gage, Mall, Minot, and other leading anatomists, the society is at present doing much to develop scientific anatomy.

The morphological direction which biology took in America during the eighties produced a large number of zoologists interested in certain

aspects of comparative anatomy who failed to find in the Anatomical Society congenial association. This was due in part to lack of acquaintance with and interest in the problems of human anatomy, and in part to the fact that a large number of the members of the Association of Anatomists were not productive investigators. A number of biologists, therefore, in 1890 founded the *American Morphological Society* for the presentation and discussion of new or important facts in the department of animal morphology and limited the membership to active contributors in that field of work. The founders of the society were, E. A. Andrews, associate professor in biology, Johns Hopkins University; Howard Ayers, late president of the University of Cincinnati; H. C. Bumpus, director American Museum of Natural History; S. F. Clarke, professor of natural history, Williams College; Dr. E. G. Gardner, Boston, Mass.; Dr. A. Hyatt, curator, Boston Society of Natural History; F. P. Mall, professor of anatomy, Johns Hopkins University; E. L. Mark, Hersey professor of anatomy and director of the zoological laboratory, Harvard University; J. P. McMurrich, professor of anatomy, University of Michigan; C. S. Minot, professor of histology and human embryology, Harvard University; T. H. Morgan, professor of zoology, Columbia University; E. S. Morse, director of Peabody Academy of Science; H. F. Osborn, professor of zoology, Columbia University; G. H. Parker, assistant professor of zoology, Harvard University; W. M. Rankin, assistant professor of biology, Princeton University; S. H. Scudder, Cambridge, Mass.; S. I. Smith, professor of comparative anatomy, Yale University; Dr. S. Watase, Imperial University, Tokio, Japan; W. M. Wheeler, curator of invertebrate zoology, American Museum; C. O. Whitman, head-professor of zoology, University of Chicago; E. B. Wilson, professor of zoology, Columbia University; and R. Ramsey Wright, professor of biology, University of Toronto.

The presidents have been C. O. Whitman, from 1890 to 1894; E. B. Wilson, for 1894-5; E. L. Mark, for 1895-6; C. S. Minot, for 1896-7; H. F. Osborn, for 1897-8; E. G. Conklin, for 1898-9; T. H. Morgan, for 1899-0; J. S. Kingsley, for 1900-1.

After a most useful career of twelve years the society was finally, in 1902, reorganized as the American Society of Zoologists, with two branches, an Eastern and a Central. The scientific development of the Association of American Anatomists has at the same time attracted into its membership a considerable proportion of zoologists interested in anatomical problems.

In 1901 the American Paleontological Society, Section A—Vertebrata, was formed. The organization of this society gives expression to a line of scientific activity that has been prominent in America for

over a century and in which Americans have been among the world-leaders. For 1905 W. B. Scott is president and Marcus S. Farr, secretary.

38. (p. 101). JOURNALS.

Articles relating to human anatomy have always been received by the leading medical journals. The first of these was the *New York Medical Repository*, founded in 1797. Thacher (*American Medical Biography*) gives a list of some twenty journals established previous to 1828. Since then the number of journals which have been established and maintained for a greater or less length of time is very great. Of these various journals the *American Journal of the Medical Sciences* of Philadelphia and *The Johns Hopkins Hospital Bulletin and Reports* of Baltimore have contained numerous scientific contributions to anatomy. The Bulletin has furnished several anatomical numbers. Other medical journals have also published contributions of importance to anatomy. Among these may be mentioned the *Journal of the Boston Society of Medical Sciences*, the *Boston Medical and Surgical Journal* and the *Journal of Medical Research*, of Boston; *The New York Medical Journal*, *Journal of Obstetrics*, *Journal of Experimental Medicine*, *Journal of Mental and Nervous Diseases* and the *Journal of Neurology and Psychiatry*, of New York; the *Annals of Surgery* and *University of Pennsylvania Medical Bulletin*, of Philadelphia; and the *Journal of the American Medical Association*, of Chicago.

The *American Anthropologist* and other publications devoted to Anthropology have contained numerous articles of value on physical anthropology.

The publications of museums and of various learned societies, municipal, state and national, and the special publications of various educational institutions have offered opportunity for the publication of articles on anatomy. Of these the publications of the Boston Society of Natural History and the Bulletins of the Museum of Comparative Zoology at Cambridge contain the greatest number of articles on anatomical subjects, paleontology excepted.

In 1818 Professor Stilliman of Yale commenced the publication of the *American Journal of Science*. This journal for nearly a century has been a potent means of stimulating scientific research. It has, however, been devoted rather to chemistry and mineralogy than to biology.

The establishment of the *American Naturalist* by A. S. Packard, C. S. Morse, A. Hyatt and F. W. Putnam in 1867, filled a growing need of a

journal for the publication of articles by those interested in natural history. Under the editorship of Packard, Cope and Kingsley it proved of the greatest value to American biology. A considerable number of important articles on anatomical problems treated from the biological standpoint have appeared in this journal.

The swing toward morphological problems which distinguished the development of zoology in this country during the eighties led in 1887 to the establishment of the *Journal of Morphology* with C. O. Whitman as editor and E. P. Allis as co-editor and chief financial supporter. This journal did much to encourage scientific work in America and to call the attention of European biologists to the progress here being made. The expense of carrying it on proved so great that in 1900 it was discontinued. Fortunately it is announced that its publication will soon be resumed.

In 1891 C. L. Herrick established the *Journal of Comparative Neurology*. The chief work of carrying on the journal has fallen, however, upon the shoulders of his brother, C. J. Herrick, Professor of Biology, Denison University, Granville, Ohio, who has earned the gratitude of all Americans interested in scientific neurology for the aid thus given to its advance. In 1903 the scope of the journal was extended so as to include comparative psychology and R. M. Yerkes and H. S. Jennings became associated with C. J. Herrick and O. S. Strong in its management.

Several journals on microscopy have been published in this country, most of them of a very "popular" nature. The most important of them, the *American Monthly Microscopical Journal*, contains some articles of interest to professional anatomists. In 1898 the *Journal of Applied Microscopy* was established at Rochester with the support of the Bausch & Lomb Optical Company. This journal was devoted more especially to microscopic technique and published a considerable number of valuable articles on this subject. Owing to the expense involved in maintaining the journal it was discontinued in 1903.

In 1899 the *Biological Bulletin* was established to serve primarily as a place for publication of brief articles on work done at the Marine Biological Laboratory at Woods Hole. It has been edited by the Director and Staff of the Laboratory and since 1902 has been under the active editorship of F. R. Lillie. Much of the work there published is based on studies of organic structure.

In 1901 the *American Journal of Anatomy* was established by G. S. Huntington, F. P. Mall and C. S. Minot, with whom are associated as editors, L. F. Barker, T. Dwight, S. H. Gage, G. C. Huber, G. S. Piersol, J. P. McMurrich and J. L. Flint. The business management of the jour-

nal is in the hands of the Secretary of the Editorial Board, Dr. H. Mc E. Knower. Many generous friends have aided the editors in establishing an endowment fund for the journal. It has assumed a high character and has been classed by Waldeyer (Merkel-Bonnet, *Ergebnisse*, 1903) as of a merit equal to that of the better European journals. The journal is the official organ of the Association of American Anatomists.

In 1904 the *Journal of Experimental Zoology* was established with the following editors: W. K. Brooks, W. E. Castle, E. G. Conklin, C. B. Davenport, R. G. Harrison, H. S. Jennings, J. Loeb, T. H. Morgan, G. H. Parker, C. O. Whitman, and E. B. Wilson. R. G. Harrison is the managing editor. This journal is the natural expression of the great activity which has been shown of recent years by Americans, especially those mentioned above as editors, in the field of experimental morphology. It marks a new step in advance.

Mention should be likewise made of the fact that C. B. Davenport is one of the three active editors of the new journal, *Biometrika*, published in London. This journal deals with statistical methods of study of biological problems.

39, (p. 103). SPECIAL HUMAN ANATOMY.

History of anatomy: Numerous addresses have been published by Americans. Of these W. W. Keen's "Sketch of the Early History of Practical Anatomy," Philadelphia, 1874, is of special value because of the light it throws on the conditions in the English schools of the eighteenth century from which the American schools arose. E. M. Hartwell has likewise made a good contribution in his "The Study of Human Anatomy." (Studies from the Biological Laboratory, Baltimore, 1881.) A most valuable account of the history of anatomy in America is to be found in W. W. Keen's "The Philadelphia School of Anatomy" (1875). E. M. Hartwell also has published a valuable paper in his "Hindrances to Anatomical Study in the United States" (*Annals of Anatomy and Surgery*, Brooklyn, 1881). Carson's *History of the Medical Department of the University of Pennsylvania* may likewise be consulted with advantage.

Text-books: A considerable number of text-books on descriptive human anatomy have been compiled by Americans but none of them have the popularity in this country of the leading English anatomies and none, so far as I am aware, have been used outside of the United States. Among the more recent authors may be mentioned H. Allen, *Human Anatomy* (1882); J. Leidy, *Human Anatomy* (1889); Brock-

way and O'Malley, *Human Anatomy* (1892); F. H. Gerrish, *Text-Book of Anatomy by American Authors* (2d ed., 1902).

L. F. Barker has translated into English Spalteholz's valuable *Hand Atlas of Human Anatomy* (1901-1903).

Of *manuals of dissection* may be mentioned those of F. D. Weisse (1886, *Practical Human Anatomy*, a book of great merit and originality), A. Hewson (1893), C. Heath (1893), W. A. Campbell (1895), I. S. Haynes (1896), W. T. and C. D. Eckley (1903), and the recent excellent "*Laboratory Manual of Anatomy*" by L. F. Barker (1904).

Articles on methods of teaching and study have within recent years been published by H. Allen (1891), F. Baker (1884, 1887), C. R. Bardeen (1900), L. F. Barker (1901), A. D. Bevan (1892), W. D. Carr (1892), T. Dwight (1890, 1891, 1895), F. H. Gerrish (1895), G. S. Huntington (1898, 1899, 1901), C. M. Jackson (1901), W. W. Keen (1881), W. Keiler (1894), F. P. Mall (1895, 1899, 1905), G. H. Minks (1885), J. P. McMurrich (1899), W. Osler (1894), W. Pepper (1894), A. Primrose (1894), R. Rayburn (1891), W. Shields (1894), and R. J. Terry (1904).

Text-books on surgical anatomy have been written by J. B. Deaver (1900-1904), and G. McClellan (1892), on clinical anatomy by D. N. Eisendrath (1903), and on artistic anatomy by G. McClellan (1901). T. Dwight published in 1881 "*The Frozen Sections of a Child*." Many of the more recent text-books on special branches of surgery have excellent chapters on the anatomy of certain areas of the body. J. W. Williams' "*Obstetrics*" and H. A. Kelley's "*Gynecology*" may here especially be mentioned. Many articles on surgical operations have likewise contained good accounts of the anatomy of special regions.

Articles on preparation, preservation and use of anatomical material and specimens have been written by J. L. Flint (1905), A. Hewson (1892), E. W. Holmes (1897), W. W. Keen (1873), W. Keiler (1892), A. T. Kerr (1901), F. P. Mall (1896), R. Park (1882), R. W. Roosevelt (1889), R. J. Terry (1902), and several others. (See especially F. P. Mall, *Johns Hopkins Bulletin*, May-June, 1896, and 1905; and *Committee Assn. Am. Anat., Science*, vol. 3, 1896.)

Papers on the anatomy and the frequency of structural variation of the various organic systems in man have been written by the following:

Skeletal system: H. Allen, C. R. Bardeen, F. Brockway, J. D. Bryant, G. R. Butler, E. B. Clinton, E. R. Corson, T. Dwight, A. Hrdlicka, P. P. Lardlaw, J. Leidy, R. W. Lovett, F. Mall, J. H. Packard, C. A. Parker, F. J. Shephard, E. A. Taylor, R. T. Terry, G. Walker, J. A. Wyeth.

Muscular system: H. Allen, E. A. Ballock, F. Baker, H. A. Christian,

Clarkson, J. D. Craig, J. B. Deaver, T. Dwight, W. S. Forbes, A. Harrison, G. S. Huntington, W. W. Keen, W. G. Lee, J. Leidy, W. H. Lewis, J. P. McMurrich, F. J. Shephard, W. H. White, J. S. Wight, and T. Wilson.

Vascular system: F. Baker, R. B. Bean, W. Browning, J. D. Bryant, W. Coleman, J. B. Deaver, T. Dwight, J. M. Hitzrot, W. Keiller, and F. J. Shephard.

The blood: L. F. Barker, G. C. Huber, F. T. Lewis, G. T. Kemp, C. S. Minot, W. Moser, W. Osler, and M. C. White.

Genito-urinary system: M. Brödel, V. Carnett, J. G. Clark, H. C. Coe, T. S. Cullen, G. C. Huber, G. L. Hunner, D. S. Lamb, E. Martin, C. S. Minot, J. P. Morse, G. A. Piersol, G. Walker, J. W. Webster, and J. W. Williams.

Alimentary tract and abdomen: C. B. Ball, R. B. Bensley, J. A. Blake, C. S. Coakley, C. H. Harvey, A. W. Hewlett, E. Hodenpyl, G. H. Huntington, C. N. Johnson, W. B. Johnston, D. S. Lamb, F. P. Mall, T. H. Manley, R. O. Moody, D. G. Revell, Byron Robinson.

Respiratory tract and thorax: H. J. Bigelow, J. A. Blake, W. T. Councilman, F. Delafield, G. S. Huntington, W. W. Keen, D. D. Lewis, W. S. Miller, H. J. Prentiss, J. W. Roosevelt, C. Seiler, and E. A. Spitzka.

The skin and glands: T. S. McGillienday, G. C. Huber, W. Keiler, C. S. Minot, R. B. Morrison, H. H. Wilder.

Nervous system: Donaldson's "Growth of the Brain" (1895), contains much useful information about the adult as well as the growing brain. R. H. Whitehead has written a small book on "The Anatomy of the Brain." M. Allen Starr, O. S. Strong and E. Leaming have published an atlas of nerve cells (1897). F. R. Sabin (1901) has contributed a standard "Atlas of the Medulla and Midbrain." L. F. Barker (1899), a text-book on "The Nervous System and Its Constituent Neurons," and H. C. Gordinier (1899), a text-book on the "Gross and Minute Anatomy of the Central Nervous System."

Among those who have contributed special articles on the peripheral nervous system of man may be mentioned: C. R. Bardeen, L. F. Barker, C. J. Blake, H. Cushing, C. L. Dana, A. W. Elting, C. E. Ingelbert, J. P. McMurrich, Newton, W. F. Norris, M. Allen Starr, J. Wallace, and J. F. Walsh.

Among those who have contributed to the anatomy of the human central nervous system may be mentioned: R. B. Bean, H. J. Berkley, J. E. Blake, W. Browning, Brown-Sequard, A. Church, C. L. Dana, F. X. Dereum, H. H. Donalson, H. A. Fowler, B. B. Gallaudet, E. Goodall, Alice Hamilton, G. S. Huntington, F. P. Mall, McLane Hamilton, E. L.

Mellus, A. Meyer, C. K. Mills, F. R. Sabin, B. Sachs, M. G. Schlapp, E. C. Seguin, W. G. Spiller, E. A. Spitzka, E. C. Spitzka, M. Allen Starr, O. S. Strong, H. D. Thompson, W. H. White, B. G. Wilder, and W. L. Worcester.

Development: The following have published papers on human embryology: C. R. Bardeen, J. M. Berry, J. L. Bremer, M. Broedel, J. G. Clark, S. P. Gage, R. G. Harrison, W. F. Hendrickson, F. Hinman, C. M. Jackson, W. W. Keen, W. H. Lewis, J. B. MacCallum, F. P. Mall, A. W. Meyers, C. S. Minot, R. M. Pearce, A. G. Pohlman, F. R. Sabin, H. D. Schmidt, G. L. Streeter, M. T. Sudler, H. E. Walter, R. Weil, E. V. Wilcox.

The following are a few among the many who have published papers describing cases of marked abnormality in development: H. Allen, F. H. Allen, F. Baker, W. E. Baldwin, E. E. Bancroft, B. Bigelow, R. L. Bowles, G. Bull, J. C. Carson, J. G. Clark, H. C. Coe, J. D. Craig, M. H. Dean, T. Dwight, L. Freeman, W. J. Fairchild, G. H. Fisher, C. M. Green, H. D. Hamilton, R. G. Harrison, L. Hektoen, B. C. Hirst, G. A. Hamman, W. T. Howard, T. Hubbard, J. Kaufmann, C. M. Kennedy, F. E. Lloyd, J. W. S. McCullough, A. McDiarmid, W. A. MacFarlane, W. G. MacCallum, J. M. Mathews, W. F. Milroy, W. Moser, A. S. Morton, T. H. Myers, W. P. Northrup, J. C. Oliver, W. Osler, D. L. Paine, R. Park, C. B. Penrose, J. C. Perry, G. A. Piersol, A. Primrose, A. Prince, R. H. Sayre, G. G. Sears, E. T. Shelley, G. E. Shoemaker, A. J. Smith, M. M. Smith, L. B. Snow, W. A. Sprigg, R. T. Terry, J. S. Thatcher, P. Thorndike, C. W. Townsend, W. S. Wadsworth, W. H. White, H. H. Wilder, H. S. Williams, T. Wilson, R. H. Wood.

Variation: The following have made studies of variation in human structure from the standpoint of age, sex and race: H. Allen, C. R. Bardeen, R. B. Bean, H. G. Beyer, F. Boas, H. P. Bowditch, D. G. Brinton, G. A. Dorsey, T. Dwight, A. W. Elting, B. A. Gould, W. W. Hastings, E. Hitchcock, A. Hrdlicka, F. P. Mall, W. D. Matthews, W. T. Porter, W. Z. Ripley, F. Russell, D. K. Shute, E. A. Spitzka, F. Tuckerman, G. M. West, H. H. Wilder.

W. H. Holmes, J. Leidy, W. D. Whitney, and others, have described supposedly ancient human bones.

B. G. Wilder has long advocated an original and simplified system of nomenclature for the central nervous system. He has gained a few partial adherents to this. L. F. Barker has had more success in introducing into use in this country the new nomenclature adopted by the German Society of Anatomists.

The above lists of names, like those of the following notes, have been derived primarily from the general indices of Schwalbe's *Anatomische*

Jahresberichte for the years 1872-1901. Some other names have been added but the lists by no means include the names of all Americans who have contributed articles of greater or less merit on the various subjects mentioned. Classification of papers is likewise difficult. Those who have been classed as contributing to one subject, because of the titles of their papers, often have in reality contributed to several related fields of knowledge. It is believed, however, that the lists mentioned in this and the following notes may prove of interest because they show what fields of anatomy have been most cultivated by Americans and the considerable numbers that have worked in certain fields.

40, (p. 108). COMPARATIVE ANATOMY OF VERTEBRATES.

W. H. Howell has written a descriptive anatomy of "The Dog" (1888), Reighard and Jennings have written one on "The Cat" (1901), Wilder and Gage on the cat in "Anatomical Technology" (1882), and H. Jayne an extensive description of the skeleton of the cat in "Mammalian Anatomy as Preparation for Human and Comparative Anatomy" (Philadelphia, 1898). A. Davison and Gorham and Tower have also published text-books on "The Cat." J. M. Fadyeau has published (1904) an "Anatomy of the Horse, a Dissector's Guide." R. W. Shufeldt (1890), has published a book on the "Myology of the Raven." A. Wiley has written a book on *Amphioxus* and the life history of the vertebrates (1894). J. S. Kingsley's *Vertebrate Zoology* (1899), is an interesting treatise on comparative anatomy and embryology. H. N. Martin and W. A. Moale published early in the eighties, useful guides for dissecting the turtle, the pigeon and the rat. Special mention should be made of G. H. Huntington's "Anatomy of the Peritoneum" (1903), an extensive comparative study.

Until within the last twenty-five years the bulk of the work done in gross comparative anatomy in America has been from the point of view of specific characteristics and genetic relationships. Among the more recent contributors to this field of the comparative vertebrate anatomy may be mentioned: A. Agassiz, L. Agassiz, H. Allen, E. P. Allis, B. A. Bensley, G. Baur, H. C. Chapman, J. D. Dana, B. Dean, C. H. Eigenman, H. H. Field, W. K. Gregory, D. S. Jordan, T. Gill, O. P. Hay, J. S. Kingsley, F. A. Lucas, E. L. Mark, J. P. Moore, E. S. Morse, H. F. Osborn, W. Patten, A. M. Reese, J. A. Ryder, A. E. Shipley, R. W. Shufeldt, R. J. Terry, J. K. Thatcher, B. G. Wilder.

In the field of vertebrate paleontology Americans have been unusually active for a century. Among the more recent workers are: C. J.

Adams, C. Austin, G. Baur, E. W. Claypole, W. B. Clapp, E. D. Cope, B. Dean, C. R. Eastman, D. G. Elliot, M. S. Farr, T. Gill, J. B. Hatcher, O. P. Hay, A. Hyatt, C. R. Keyes, W. C. Knight, J. Leidy, F. B. Loomis, R. S. Lull, F. A. Lucas, O. C. Marsh, W. D. Matthew, J. C. Merriam, E. S. Morse, H. F. Osborn, W. Patten, E. S. Riggs, W. B. Scott, R. W. Shufeldt, C. H. Sinclair, A. Stewart, C. Walcott, S. W. Williston.

Comparative study of the gross anatomy of various organic systems of various vertebrates has been made by the following: H. Allen, E. P. Allis, H. Ayres, F. Baker, J. L. Bremer, A. L. Bruner, C. Carmalt, E. J. Claypole, C. B. Davenport, F. K. Davis, A. Davidson, B. Dean, F. Dercum, F. Dexter, C. L. Edwards, C. H. Eigenmann, S. H. Gage, T. H. Gill, W. A. Hilton, Ida Hyde, G. S. Hopkins, G. S. Huntington, C. M. Jackson, H. Jayne, G. E. Johnson, J. S. Kingsley, H. M. Lane, C. F. W. McClure, J. P. McMurrich, W. S. Miller, R. O. Moody, E. S. Morse, E. F. Muhse, Florence Mayo, G. H. Parker, W. E. Ritter, F. J. Shephard, J. R. Slonaker, F. Smith, C. F. Sylvester, F. W. True, H. H. Wilder, S. R. Williams, I. S. Workman.

Contributions to comparative neurology are spoken of specially in note 44, p. 202.

The following Americans have added to our knowledge of the microscopic structure of vertebrate organs: R. R. Andrews, C. R. Bardeen, R. R. Bensley, W. J. Calvert, B. A. Cohoe, Lydia M. DeWitt, G. Eisen, J. M. Flint, S. H. Gage, H. R. Harrington, W. F. Hendrickson, G. S. Hopkins, G. L. Houser, G. C. Huber, B. F. Kingsbury, P. Kyes, F. P. Mall, W. S. Miller, C. S. Minot, T. W. Montgomery, E. L. Opie, R. M. Pearce, D. G. Revell, F. Schmitter, G. Walker, A. S. Warthin, F. G. White. For text-books on this subject see note 41.

(See concluding paragraph, note 39, p. 197.)

41. (p. 110). COMPARATIVE HISTOLOGY.

T. E. Satterthwaite in 1882 edited a good manual of histology by American authors. References to American literature are here given. T. C. Prudden (1888), G. A. Piersol (1893), and E. K. Dunham (1900), have successfully written popular text-books on this subject. J. S. Ferguson has recently brought out another (1905). J. B. MacCallum (1902) has translated with annotations the *Histology and Microscopic Anatomy* written by L. Szmonowicz, and G. C. Huber (2nd ed., 1904), that of Boehm and von Davidoff. S. H. Gage and B. F. Kingsbury have published a laboratory guide for vertebrate histology (1900).

Among the many contributions on the subject of the structure of

vertebrate tissues may be mentioned those of: A. Agassiz, B. M. Allen, R. R. Andrews, C. R. Bardeen, L. F. Barker, H. P. Bowditch, R. H. Chittenden, G. Eisen, A. C. Eycleshymer, J. M. Flint, S. H. Gage, S. P. Gage, I. M. Green, C. Heitzmann, A. E. Hertzler, W. H. Howell, G. C. Huber, A. B. Macallum, J. B. MacCallum, W. G. MacCallum, F. P. Mall, W. S. Miller, C. S. Minot, W. Osler, J. A. Ryder, H. D. Schmidt, A. P. Matthews, C. Sihler, F. Schmitter, T. E. Satterthwaite, W. H. Welch, and M. C. White.

Those who have contributed to the histology of the nervous system are mentioned in Note 44, p. 202.

There have been fewer real contributions to microscopic technique than would have been expected from a nation so inventive as the American. Text-books on histological technique have been written by I. Hardesty, C. O. Whitman, S. H. Gage, and others. A number of more or less useful technical methods and devices have been brought out by the following workers: C. R. Bardeen, H. J. Berkeley, C. E. Bessey, H. C. Bumpus, T. Cullen, U. O. Cox, A. C. Eycleshymer, J. M. Flint, G. C. Freeborn, S. H. Gage, H. R. Gaylord, I. Van Gieson, I. Hardesty, A. F. Harris, C. J. Herrick, A. G. Hoen, G. C. Huber, F. M. MacFarland, F. B. Mallory, A. Meyer, C. S. Minot, V. A. Moore, B. D. Myers, C. A. Oliver, G. H. Parker, J. W. Roosevelt, C. Sihler, J. R. Slonaker, G. L. Streeter, R. Tolles, J. C. Webster, W. F. Whitney, W. M. Mac Woodworth, J. H. Wright.

(See concluding paragraph, Note 39, p. 197.)

42, (p. 111). CYTOLOGY.

The American literature on the cell is well treated in Wilson's text-book, "The Cell in Development and Inheritance" (1900).

Of those who have contributed papers on the more general features of the cell and the cell theory of structure, mention may be made of E. A. Andrews, G. F. Andrews, G. N. Calkins, C. M. Child, E. G. Conklin, H. E. Crampton, L. I. Dublin, A. C. Eycleshymer, K. Foot, M. F. Guyer, H. P. Johnson, B. F. Kingsbury, A. A. Lawson, F. R. Lillie, R. S. Lillie, A. B. MacCallum, E. L. Mark, A. P. Matthews, C. E. McClung, A. D. Mead, C. S. Minot, T. H. Montgomery, T. H. Morgan, W. S. Sutton, C. O. Whitman, and E. B. Wilson.

C. Heitzmann and C. O. Whitman have contended strongly against the adequacy of the cell theory of development.

The following botanists have made important contributions to the knowledge of the structure of plant cells and especially of cell divi-

sion: C. E. Allen, F. M. Andrews, G. F. Atkinson, D. H. Campbell, W. A. Cannan, C. J. Chamberlain, B. M. Davis, T. C. Frye, B. B. Griffin, R. A. Harper, D. S. Johnson, A. A. Lawson, F. M. Lyon, D. M. Mottier, W. J. V. Osterhout, J. B. Overton, E. W. Olive, W. A. Setchell, J. H. Shaffner, F. L. Stevens, R. Thaxter, C. O. Townsend, and H. J. Webber.
(See concluding paragraph, note 39, p. 197.)

43, (p. 111). EMBRYOLOGY OF VERTEBRATES.

Several text-books have been written on this subject by Americans. Foremost stands C. S. Minot's "Human Embryology" (1892), which is essentially a treatise on comparative vertebrate embryology. Minot's "Bibliography of Vertebrate Embryology" (1893), is also of the greatest help to workers in that field. Minot has recently (1903) published a "Laboratory Text-book of Embryology," based on the pig. J. P. McMurrich (1903) has written a good text-book on "Human Embryology," from the standpoint of comparative anatomy. E. L. Mark (1893) has translated Hertwig's "Embryology." J. C. Heisler (1899) has written a text-book on "Human Embryology." T. H. Morgan has published a valuable book on the "Development of the Frog's Egg" (1897). E. B. Wilson's "The Cell" contains much information about the sex-cells and fertilization. The atlas of the fertilization and karyokinesis of the ovum by Wilson and Leaming is a fine contribution. F. R. Lillie (1904) has written a useful laboratory outline guide on the embryology of the chick and pig. A. M. Reese has likewise written a college text-book on vertebrate embryology.

Among those who have contributed to the subject of formation of the sex-cells, fertilization and cleavage in animals are: A. Agassiz, L. Agassiz, E. A. Andrews, G. F. Andrews, F. W. Bancroft, E. R. Boyer, E. W. MacBride, Martha Bunting, G. N. Calkins, A. J. Carlson, W. E. Castle, C. M. Child, E. G. Conklin, A. M. Claypole, L. Dublin, C. H. Eigenmann, G. Eisen, A. C. Eycleshymer, G. W. Field, K. Foot, M. F. Guyer, C. W. Hargitt, B. N. Harper, E. H. Harper, F. H. Herrick, M. Hold, H. S. Jennings, H. B. Johnson, E. O. Jordan, H. D. King, B. F. Kingsbury, J. S. Kingsley, C. A. Kofoed, T. G. Lee, G. Lefevre, F. R. Lillie, C. E. McClung, J. H. MacGregor, W. A. MacFarland, E. L. Mark, A. D. Mead, C. S. Minot, W. H. Moenkhaus, T. H. Montgomery, J. P. Moore, T. H. Morgan, J. P. Munson, H. F. Osborn, E. F. Phillips, A. M. Reese, J. A. Ryder, J. E. Reighard, W. B. Scott, E. G. Spaulding, W. S. Sutton, S. Watase, A. W. Weyse, W. M. Wheeler, R. G. Whitehead, C. O. Whitman, E. V. Wilcox, C. B. Wilson, H. V. Wilson, F. A. Woods, and N. Yatsu.

Among those who have contributed papers on specific characteristic structural differentiation in various classes of vertebrates are: A. Agassiz, L. Agassiz, H. Allen, C. M. Clapp, H. J. Clark, S. F. Clarke, B. Dean, C. H. Eigenmann, A. C. Eycleshymer, H. Fox, E. H. Gregory, Jr., E. O. Jordan, P. B. Hoy, W. E. Kellicott, J. S. Kingsley, F. D. Lambert, F. R. Lillie, E. W. MacBride, J. H. McGregor, E. L. Mark, T. H. Morgan, H. Orr, F. Peebles, J. E. Reighard, H. J. Rice, W. H. Ritter, J. A. Ryder, L. V. Sampson, W. B. Scott, F. B. Summer, L. Wallace, C. O. Whitman, S. R. Williams, H. V. Wilson, J. Wyman.

The foetal membranes have been studied among others by: H. Ayres, T. G. Lee, F. R. Lillie, F. P. Mall, C. S. Minot, H. F. Osborn, and J. A. Ryder.

Among those who have contributed to the study of comparative vertebrate organo-genesis and histogenesis are: B. M. Allen, H. Ayres, C. R. Bardeen, J. M. Berry, E. R. Boyer, J. L. Bremer, W. K. Brooks, J. G. Clark, S. F. Clarke, H. E. Crampton, A. Davidson, F. Dexter, A. C. Eycleshymer, C. H. Eigenmann, H. H. Field, J. M. Flint, H. Fox, S. H. Gage, S. P. Gage, R. W. Hall, R. G. Harrison, M. Hempstead, W. F. Hendrickson, C. Hill, D. C. Hilton, W. A. Hilton, A. T. Holbrook, O. P. Hay, W. H. Howell, G. C. Huber, D. Hunt, C. M. Jackson, J. B. Johnson, E. O. Jordan, J. S. Kingsley, A. B. Lamb, F. T. Lewis, F. R. Lillie, E. W. MacBride, J. B. MacCallum, F. P. Mall, A. M. Miller, W. S. Miller, C. S. Minot, T. H. Morgan, H. V. Neal, H. W. Norris, H. F. Osborn, G. H. Parker, F. Peebles, G. A. Piersol, J. B. Platt, G. C. Price, M. A. Reed, R. M. Reese, M. J. Ross, J. A. Ryder, F. R. Sabin, L. V. Sampson, T. E. Satterthwaite, H. Sewell, A. M. Spurgon, R. M. Strong, E. Taylor, G. H. Tozier, A. H. Tuttle, J. Warren, R. G. Whitehead, and H. V. Wilson.

(See concluding paragraph, Note 38, p. 197.)

44. (p. 112). COMPARATIVE NEUROLOGY.

Text-books dealing with the comparative anatomy of the nervous system have been written by H. H. Donaldson, "The Growth of the Brain" (1895), and L. F. Barker, "The Nervous System" (1899).

The following have contributed articles relating to the comparative gross and microscopic anatomy and development of the central nervous system of vertebrates: H. Ayers, Jessie Allen, W. S. Baer, W. Barnes, J. H. Bawden, Brill, W. P. Carr, B. Clark, T. E. Clarke, H. C. Chapman, S. V. Cleavenger, G. C. Davenport, P. M. Dawson, F. Dexter, H. H. Donaldson, A. C. Eycleshymer, P. A. Fish, Alice Hamilton, G. M. Hammond, C. J. Herrick, C. L. Herrick, J. B. Johnston, B. F. Kingsbury, J. S.

Kingsley, W. W. Lesem, W. A. Locy, J. Loeb, S. D. Ludlum, H. T. Marshall, J. J. Mason, F. W. McClure, E. L. Mellus, A. Meyer, H. V. Neal, I. Nakagawa, H. F. Osborn, Pemberton, W. F. Porter, E. E. Ranney, S. W. Ranson, P. E. Sargent, E. A. Spitzka, E. C. Spitzka, B. B. Stroud, E. A. Taylor, B. G. Wilder.

The following have written papers on the structure, distribution and development of the peripheral nervous system: W. C. Ayres, C. R. Bardeen, E. A. Birge, M. A. Bowers, H. E. Cogher, Lydia M. DeWitt, E. H. Dunn, H. Fox, H. A. Green, R. G. Harrison, C. J. Herrick, W. H. Howell, G. C. Huber, G. L. Houser, J. S. Kingsley, A. J. Lanterman, W. A. Locy, H. V. Neal, C. W. Prentiss, J. J. Putnam, H. D. Schmidt, T. B. Spence, G. L. Streater, O. S. Strong, T. B. Stowell and F. C. Waite.

The following have studied more particularly the finer structure of the nerve cell: L. F. Barker, H. J. Berkley, U. Dahlgren, I. Herdesty, S. Hatai, C. F. Hodge, G. L. Houser, G. C. Huber, C. F. W. McClure, A. Meyer, F. B. Mallory, Margaret L. Nickerson, S. Paton, W. C. Prentiss, P. Sargent, M. Allen Starr and O. S. Strong.

The following have contributed to the knowledge of nerve endings: E. P. Allis, Jr., H. J. Berkley, F. S. Bunker, G. E. Coghill, L. M. DeWitt, G. C. Huber, M. L. Nickerson, C. Sihler, A. L. Treadwell, and J. H. Wilson.

The following have studied the finer structure of the eye: B. M. Allen, W. C. Ayers, E. L. Berger, C. H. Eigenmann, D. Hunt, F. P. Mall, B. D. Myers, G. A. Piersol, R. L. Randolph, J. R. Slonaker.

The following have studied the comparative anatomy and the development of the ear: H. Ayers, L. Howe, D. Hunt, J. S. Kingsley, F. P. Mall, A. D. Morrill, H. W. Norris, G. E. Shambaugh, T. B. Spence, A. H. Tuttle.

The following have contributed papers on the organs of smell and taste: H. H. Bawden, A. Hamilton, and F. Tuckerman.

The following have written on neurological technique; H. J. Berkley, I. Van Gieson, I. Hardesty, C. J. Herrick, G. L. Houser, G. C. Huber, and F. B. Mallory.

(See concluding paragraph, Note 39, p. 197.)

45. (p. 113). EXPERIMENTAL MORPHOLOGY.

C. B. Davenport has written a text-book on "Experimental Morphology" (1897-99), J. Loeb, one on physiological morphology (1891-2), and T. H. Morgan, one on "Regeneration" (1901).

Experimental studies on the formative capacity of various parts of

the ovum have been conducted by: E. G. Conklin, H. E. Crampton, F. R. Lillie, J. Loeb, T. H. Morgan, F. Peebles, E. B. Wilson, N. Yatsu, and C. Zeleny.

The power of regeneration in invertebrates and the factors concerned have been investigated by: C. R. Bardeen, E. E. Bickford, A. M. Boring, C. M. Child, W. C. Curtis, C. B. Davenport, S. E. Davis, S. Flexner, G. L. Hargitt, C. W. Hargitt, A. P. Hazen, V. L. Kellogg, H. D. King, G. Lefevre, F. R. Lillie, J. Loeb, T. H. Morgan, F. Peebles, H. W. Rand, H. Randolph, M. A. Reed, H. T. Rowley, N. M. Stevens, H. F. Thatcher, E. W. Towle, J. Van Duyne, C. O. Whitman, E. B. Wilson, C. Zeleny.

The effects of altering the chemical media surrounding ova have been studied by: G. Bullo, C. B. Davenport, G. C. Davenport, M. H. Fisher, S. J. Hunter, G. Lefevre, W. H. Lewis, F. R. Lillie, R. S. Lillie, J. Loeb, A. P. Mathews, W. W. Norman, A. L. Treadwell.

The effects of physical agents acting on developing organisms, by: C. R. Bardeen, H. Baetjer, C. B. Davenport, C. L. Edwards, P. S. Gilman, A. W. Greeley, J. Loeb, S. J. Meltzer.

Regeneration in vertebrates has been studied by: Baer, Dawson and Marshall, E. F. Byrnes, H. C. Cushing, R. G. Harrison, W. H. Howell and G. C. Huber, W. H. Lewis, F. P. Mall, T. H. Morgan, R. L. Randolph, S. W. Ranson and E. W. Towle.

The effects of transplantation of tissues and grafting in vertebrates have been studied by: R. G. Harrison, H. McE. Knower, W. H. Lewis, L. Loeb, F. P. Mall, T. H. Morgan, R. T. Morris, G. F. Shrady, W. H. White.

The effects of physiological activity on cell structure have been investigated by: A. J. Carlson, P. K. Gilman, and C. F. Hodge. The effects of starvation on the developing nervous system of the rat have been studied by H. Hatai, and the effects of special feeding, exercise and similar phenomena are now being studied in Professor Donaldson's laboratory. (See H. Donaldson, *Human Anatomy, Science*, Feb. 6, 1905.)

(See concluding paragraph, Note 39, p. 197.)

46. (p. 116). VARIATION.

C. B. Davenport (2d ed., 1904) has published a valuable book on statistical methods.

Statistical studies of variation in animals have been made by: C. C. Adams, E. T. Brewster, H. C. Bumpus, W. E. Castle, H. E. Crampton, C. B. Davenport, G. C. Davenport, C. H. Eigenmann, W. L. W. Field, F. E.

Lutz, W. J. Moenkhaus, G. H. Parker, J. T. Peck, M. E. Smallwood, R. M. Strong, C. O. Whitman, S. R. Williams, and R. M. Yerkes.

Breeding experiments on a large scale have been conducted by: A. G. Bell, W. E. Castle, H. E. Crampton, C. B. Davenport, Isabel McCracken, W. L. Tower, and C. O. Whitman.

In addition many valuable studies of breeding in its practical aspect have been carried on at the experimental laboratories of the agriculture stations.

(See concluding paragraph, Note 39, p. 197.)

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THE JOINT SYSTEM IN THE ROCKS OF SOUTHWESTERN
WISCONSIN AND ITS RELATION TO THE
DRAINAGE NETWORK

BY

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A THESIS SUBMITTED FOR THE DEGREE OF BACHELOR OF ARTS
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PREFATORY NOTE.

The data on which this paper is based were collected by the writer during the summer of 1904 under the direction of Professor W. H. Hobbs of the University of Wisconsin, and thanks are due to him for many suggestions on the field work as well as on the arrangement of this paper. It was also by him that the data on the joint directions round Highland, in the southern part of the Richland Center district was obtained. Acknowledgments are also due to Mr. R. C. Allen for data upon the joint directions around Iron Ridge.

E. C. H.

June, 1906.

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THE JOINT SYSTEM IN THE ROCKS OF SOUTHWEST- ERN WISCONSIN, AND ITS RELATION TO THE DRAINAGE NETWORK

PART I.

THE JOINT SYSTEM.

GEOLOGICAL FORMATIONS OF SOUTHERN WISCONSIN.

The work described in the following paper consisted in the study of joints and joint directions in three main areas in southwestern Wisconsin, and a number of minor ones scattered over the southern part of Wisconsin and the northern part of Illinois. The main areas are those around Richland Center, Richland County; Prairie du Chien, Crawford County; and Potosi, Grant County; while the minor ones are in the vicinities of Galena, Mineral Point, Milwaukee, Madison, Devils Lake, and Iron Ridge. Maps were prepared for the main districts to show the chief drainage lines and the principal joint directions in the different portions. Of the minor districts only summaries of joint directions will be given.

In all the areas except that of Devils Lake the rocks are nearly flat lying, little metamorphosed sediments of the Paleozoic. These are dominantly limestone with some sandstone and a few shales. The area around Devils Lake is mainly occupied by much folded and metamorphosed Pre-Cambrian quartzites.

The rocks of Southern Wisconsin range in age from the Archean to the Devonian with the following succession:

Devonian—Hamilton limestone.

Helderberg limestone.

Silurian—Niagara limestone.

Ordovician—Hudson River shale.

Galena limestone.

Trenton limestone.

St. Peter sandstone.

Lower Magnesian limestone.

Cambrian—Potsdam sandstone.

Algonkian—Freedom iron formation.

Seeley slate.

Baraboo quartzite.

Archean—Granite and porphyry.

All of the foregoing formations except the Hudson River shale, Freedom iron formation, Seeley slate, and Archean granite and porphyry, give good outcrops from which reliable jointing directions can be procured. Of the above four, the first and last give only a few exposures, and those very poor, and the second and third are not exposed.

The Archean granite and porphyry are exposed in a few outcrops around the Baraboo syncline. They are immediately below the Baraboo quartzite and are exposed only at points where the drift does not cover the base of the quartzite. The outcrops are very small and the joints irregular and unreliable.

The Baraboo quartzite constitutes the entire mass of the Baraboo ranges along which it is exposed everywhere in nearly vertical cliffs with talus slopes. Its joints are clear and well defined both in form and direction, and are to a very large extent nearly vertical. The joint faces and square blocks are present everywhere along the base of the cliff.

Potsdam sandstone is a basal sedimentary rock of most of southern Wisconsin. It is exposed in the valleys of all the larger rivers north of the Wisconsin and also for a small distance south of it. In the Richland Center area the Potsdam is exposed mainly in cliffs, either at the sides of the streams or on top of the ridges between the valleys. Most of the exposures may be classed with one of two hard beds, an upper and a lower. The upper bed is

exposed in the cliffs on the ridges and rises higher above the valley floor as we proceed northward. About five miles north of the Wisconsin river the lower bed appears, forming cliffs on the river banks. This layer also rises gradually as we proceed toward the north, and at the northern limit of the map forms cliffs from twenty to thirty feet in height. Between these two hard layers there are softer calcareous and shaly layers which are rarely exposed except in quarries. In the Prairie du Chien district the Potsdam is exposed only in the basal cliffs bordering the Mississippi flood plain. These are best seen on the Iowa side, for the river, being present there, has cut into the flood plain.

The joints of the natural exposures of the Potsdam are rather imperfect in form due to the weathering of the friable sandstone. In the fresh exposures such as quarries the joints are sharp and well defined. All the joints of the Potsdam are quite constant in their direction and a large majority of them are vertical.

The Lower Magnesian is exposed in most parts of southwestern Wisconsin. It is found in the bottom of the larger valleys in the southern part and grades upward as we go north until it occupies the top of the ridges in the region north of the Wisconsin river. In the Richland Center district the Lower Magnesian is found as a cap rock of the interstream ridges. It disappears entirely in the northern part of the district. In the Prairie du Chien district it forms the main part of the bluffs, and cliffs of it are found everywhere along the bluffs of the Mississippi and its side streams. It is also exposed in the beds of most of the minor streams. In the Potosi district the Lower Magnesian is exposed only in the valleys of the larger streams and at the very base of the hills bordering them.

The joints of the Lower Magnesian are in many places very imperfect in form, due to numerous concretions. In a few horizons, however, where the rock is uniformly fine textured and free from concretions, it yields very perfect joint faces.

The St. Peter sandstone is exposed to some extent all over southwestern Wisconsin, but rapidly dies out north of the Wisconsin river. In the Richland Center district it is found only on the highest divides and is there exposed in cliffs at the headwaters of small tributaries. In the Prairie du Chien district it is generally exposed in a line of low cliffs bordering the Missis-

ssippi and the lower courses of its minor branches. It is also exposed in the beds of nearly all of the streams some distance above the underlying limestone outcrops. In the Potosi district the St. Peter is exposed in cliffs along the sides of the river valleys. These outcrops grade upward as one goes northward but over most of the area they are near the bottom of the ridges.

The joints in this formation are generally well defined although not perfect. A feature which distinguishes them from the joints of all the other formations is their inclination—a large number of them dipping at angles of 10° to 30° with the vertical, while the great majority of the other joints are nearly or quite vertical. There also seems to be here a preponderance of joints trending in one or two directions and these are generally spaced at regular intervals. The form and character of the joints themselves are very much like those of the Potsdam.

The Trenton limestone is exposed very abundantly south of the Wisconsin river, but is also found north of it near its junction with the Mississippi. In the Prairie du Chien district it is found, together with some Galena limestone, as a cap rock of the entire up-country, and is exposed at the headwaters of all the streams but is rarely exposed on the bluffs. Around Potosi it is found in much the same way, except that here it has a thicker capping of Galena above it.

The Galena limestone is the cap-rock of the entire region south of the Wisconsin river except in the few areas where the mounds rise above the surrounding country. It is exposed in the stream beds like the Trenton, but also, on account of a thick flinty layer in its upper horizon, forms high cliffs on the top of the bluffs bordering the Mississippi and its branches.

The joints of the above limestones are the most perfect in the entire region. Those of the Quarry beds at the base of the Trenton are especially sharp and well defined and can often be measured within a degree. These joints, as is true of other limestone joints, are vertical almost without exception. (Plates II, III, and IV.)

The Hudson river shale is present near the summits of the mounds which are found in many parts of the driftless area in Wisconsin, Illinois, and Iowa. It is exposed in only a few places and was not present in any of the districts studied.

The Niagara is found at the summit of most of the mounds and also occupies a wide strip of country along the eastern side of the state. In the latter area it is covered with glacial drift and is rarely exposed except in quarries. Along Lake Winnebago and southward, however, its western boundary forms an escarpment due to the rapid erosion of the underlying shale.

Its joints are the most perfect ones found in any of the districts, and could be studied to some advantage because the exposures were immense quarries. Most of them ran for long distances without changing their courses in either direction, and the faces formed by them were smooth and vertical. In one or two cases however, a peculiar phenomenon was observed, namely, the joints were curved instead of straight. One case in particular was noticed where a joint swung in a gentle curve from N 75° W to N 88° E. These curved joints are not generally characteristic of the Niagara, but are unusual phenomena such as have been observed elsewhere by Russell, Gilbert, and others.

The Helderberg limestone is exposed in a few places northwest of Milwaukee. It is a thin bedded shaly rock, but its joints are poor and irregular and they are hardly distinguishable from other fractures.

The Hamilton limestone is exposed in the cement quarries north of Milwaukee. Its joints are sharp and distinct but very few in number. This scarcity is true both of the different joint series and of the total number of joints.

Observations were taken in all of the above described formations except the Archean granite and porphyry and the Hudson river shale. Exposures of the former were too small to yield reliable data, while exposures of the latter were not present in the areas studied.

PREVIOUS WORK.

Joint Directions.—Perhaps the earliest work on the joint directions of southwestern Wisconsin was done by James G. Percival¹ about 1854. He gives the principal crevice directions in each of the main diggings, that of the Potosi area being given as E 20° S (N 70° W).

¹ Ann. Rep. of the Geol. Survey of Wis., 1855.

After 1860 J. D. Whitney² took up the work in the lead region, and during his investigation he found the directions of the crevices in each of the mines. He says:

"Each group of diggings is in general characterized by main lead bearing crevices in each district being nearly parallel with each other.
* * * There is everywhere a tendency to the formation of two sets of crevices nearly at right angles to each other, but of which only one set is productive in ore, the other set being mere seams or cracks in the strata. * * * There is a close approximation throughout a large portion of the lead region to an east and west and north and south direction in the two principal sets of crevices, and farther the east and west crevices are the main productive lead bearing crevices."

In another place he gives the main crevice directions in the different diggings of the Potosi area.³

Rockville and British Hollow Diggings: N 76° W, N 66° W, N 87° W, N 78° W (2), N 0° W, N 80° W, N 30° E, N 80° E.

Potosi Diggings: N 69° W (2), N 84° W, N 71° W, N 61° W, N 63° W (2), N 82° W, N 60° W, N 68° W, N 65° W (4), N 67° W (3), N 66° W, N 55° W (3), N 70° W (3).

Red Dog Diggings: N 70° W, N 90° W.

Pin Hook Diggings: N 75° W (4), N 76° W (2), N 70° W, N 69° E.

In later years some work was done on crevice directions by Moses Strong,⁴ but the results which he obtained were like those of Percival and Whitney and so need not be considered here.

During this time Prof. T. C. Chamberlin⁵ also worked in southwestern Wisconsin, and in connection with his report were published a number of maps by James Wilson,⁶ giving the crevice directions in the different diggings of the lead region and including the Potosi area. (Plate I.)

Joint Intervals.—The regularity of joint intervals was noticed as early as 1854 by Percival⁷ in connection with his work on the mineral crevices of the mining region. He speaks of the com-

²Geol. of Wis., Vol. I, 1862; Hall & Whitney, pp. 381-383.

³Ibid., p. 329.

⁴Geol. of Wis., Chamberlin, Vols. II and IV.

⁵Ibid., Vol. IV.

⁶Atlas. Wis. Geol. Survey. T. C. Chamberlin and others.

⁷Ann. Rep. of the Geol. Survey of Wis., 1855.

bination of ranges (crevices) into groups and these groups into larger series all having a regular, definite arrangement. He says:

"On combining the different diggings it will be found that a certain order prevails in the bearing of the leading east and west ranges; the different ranges in each usually having a common bearing and a number of different diggings being found combined into more extended series by the common bearing of their ranges." [Page 76.]

Percival's east and west crevices vary as much as 45° on either side of due east and west. In another place he says:⁸

"The leading object of the detail I have given of the arrangement of the minerals in crevices and openings and of the surface arrangements of the ranges in groups and more extended combinations has been to show that a systematic order prevails throughout and that the mineral deposits are not detached and casual but combined in regular series."

At the end of the chapter he concludes:⁹

"What I have here given is only a small part of what might have been stated; but I trust it will suffice to show that the ranges in their bearing and in their grouping from the smallest to the most extended combinations have been governed by some general laws, and have not been merely local accidents. I might have stated many facts which seem to show a regularity in the distance between the different ranges in the same group; but such a statement would require a degree of detail incompatable with my present object. Such a regularity is not only probably in the arrangement of each group but in the combination of groups into larger bodies and more extended series. To determine this satisfactorily would require an exact, topographical survey of the mines, which may hereafter become an object well worthy of public attention."

Professor Chamberlin¹⁰ in his report reviews part of Dr. Percival's work and agrees with him in many points, but disagrees in others. He says:

"Much study and ingenuity, not to say imagination, have been expended in the endeavor to discover some law of systematic arrangement of the crevices into groups and larger collocations, but without any conspicuous success, as it would appear from the different results

⁸Ann. Rep. of the Geol. Survey of Wis., 1855.-98.

⁹Ibid., pp. 100-101.

¹⁰Geol. of Wis., Vol. IV, pp. 439-441.

arrived at. If there were any simple determinative law, it would seem that, if discovered, it should command general assent and acceptance. This much is certain, that individual ranges are not uniformly distributed over the productive area to which they belong but are gathered in groups. But these groups present the utmost variety in the manner and attitude of their formation. Perhaps the most noteworthy fact is that to which Dr. Percival has long since called attention, that these ranges are sometimes arranged so as to give a rhombic outline to the group, and that these groups are arrayed somewhat like groups *en echelon*. But this is only true of a few districts, the best example being the Vinegar Hill diggings. The gathering of subordinate groups into districts with barren intervals between is a conspicuous fact concerning which there is little opportunity for differences of view. But when it comes to arraying these in larger groups and showing the profounder relations of the districts, wide differences have been the result."

METHODS OF INVESTIGATION.

Methods of Field Work.—The topography of southwestern Wisconsin is that of a dissected plain where the river valleys are separated by flat interstream ridges. These ridges are wide in the southern and western part and here constitute the cultivated tracts, while the valleys are usually narrow and wooded. As we pass northward the ridges become narrower and the valleys wider, until, as in the Richland Center district, the valleys contain the farms and cultivated lands while the ridges are narrow and wooded for the most part.

The lowest rock formations in each district are exposed in the main valleys, and in going up tributary streams successive overlying formations are met with and the hard layers found exposed in the stream beds or in cliffs along the sides. From these stream-bed exposures and from quarries situated in many places throughout the country the most reliable data were obtained. Very often reliable data were obtained also from cliffs bordering the valleys or capping the summits of the bluffs or ridges.

In each one of the exposures the directions of all the well defined joints were taken with a four-inch Gurley compass. If two or more joints were found, trending in the same direction in one exposure, the duplicates were recorded by means of check marks—one for each duplicate. We are thus enabled to tell with reas-

onable accuracy the dominant joint directions in each area and, finally, in the district as a whole. The readings are, in each case, probably within a few degrees of being correct, which is about as accurate as is possible in that region.

As a rule the joints in the limestone were sharper and more clearly defined than those in the sandstone, hence the data from the former are more reliable. The joints of any series generally vary only a few degrees in direction at different points, but in exceptional cases, as those mentioned in the Niagara limestone, the variation may be as high as 15° or 20° .

In the exposures in the beds of streams and quarry floors, the joints are shown as straight fissures running across horizontal outcrops, while in cliffs and quarry walls they are shown either by smooth vertical faces or vertical and steeply inclined fissures.

Construction of Maps.—The maps of the three main districts were traced from topographic sheets of the United States Geological Survey. Only the water courses and some of the larger villages were traced on these because topography and culture lines obscure the drainage net work to a large extent. After the water courses had been mapped, the principal joint directions of the different portions of the district were added. The order of prominence of these joint directions was summarized for areas including a number of individual exposures, more or less grouped together. The degree of prominence of these is indicated in star symbols by the width of the rays, of which there are three grades.

STUDY OF JOINT DIRECTIONS.

The Prairie du Chien District (Plate II).—The Prairie du Chien district covers an area about twenty-seven miles long and sixteen miles wide. It ranges from about eleven miles south of the Wisconsin to about sixteen miles north, and extends about eight miles on either side of the Mississippi. The data on the joints of this district were obtained chiefly from the Trenton and Lower Magnesian limestones. The former was exposed mainly in stream beds and the latter in quarries. These data are summarized in the following table which shows the relative importance of each of the joints. The numbers given do not stand for

the actual number of joints found, but for the number of localities at which they were found.

Joint.	No.	Joint.	No.
N. 15° W.—13		N. 5° E.—21	
N. 25° W.—45		N. 25° E.—19	
N. 35° W.—35		N. 35° E.—34	
N. 45° W.—25		N. 45° E.—29	
N. 55° W.—35		N. 50° E.—26	
N. 65° W.—29		N. 55° E.—34	
N. 75° W.—34		N. 65° E.—19	
N. 85° W.—27		N. 75° E.—28	
		N. 85° E.—19	
		N. 90° E.—14	

The Richland Center District (Plate III).—The Richland Center district covers an area about thirty-two miles long and twenty miles wide. It ranges from eleven miles south of the Wisconsin river to twenty miles north of it. The data from this area were obtained for the most part from the Potsdam layers. About half of the data were obtained from the limestone and shaly layers exposed in the quarries, and the rest from cliffs of the upper and lower hard layers. The following table is a summary of localities in which the different joints were found:

Joint.	No.	Joint.	No.
N. 5° W.—1		N. 0° E.—7	
N. 10° W.—2		N. 5° E.—19	
N. 12° W.—2		N. 15° E.—5	
N. 15° W.—14		N. 20° E.—5	
N. 20° W.—3		N. 22° E.—2	
N. 25° W.—16		N. 25° E.—12	
N. 30° W.—5		N. 30° E.—2	
N. 35° W.—23		N. 35° E.—35	
N. 40° W.—1		N. 40° E.—1	
N. 45° W.—14		N. 45° E.—20	
N. 50° W.—5		N. 46° E.—2	
N. 55° W.—23		N. 50° E.—6	
N. 60° W.—9		N. 52° E.—1	
N. 65° W.—9		N. 55° E.—9	
N. 70° W.—5		N. 60° E.—5	
N. 72° W.—2		N. 65° E.—12	
N. 75° W.—11		N. 70° E.—5	
N. 80° W.—4		N. 72° E.—3	

N. 82° W.— 2
N. 85° W.— 5

N. 75° E.—24
N. 80° E.— 2
N. 85° E.— 9
N. 90° E.—11

The Potosi District (Plate I).—The Potosi district covers an area about fourteen miles long by nineteen miles wide, of which the village of Potosi occupies about the center. It includes a part of the Mississippi flood plain and a part of Iowa. The joint directions of this district were taken with very few exceptions from stream beds and in Trenton and Galena limestones. A few were taken from the St. Peter sandstone. The joints of the limestone are all nearly vertical and in many places those trending in the same direction are spaced at regular intervals. This is also very apparent in the sandstone, but here a large part of the joints vary by some ten or more degrees from verticality. The following table summarizes the joint directions in the Potosi district:

Joint.	No.
N. 5° W.—	3
N. 10° W.—	1
N. 15° W.—	3
N. 20° W.—	9
N. 25° W.—	4
N. 30° W.—	1
N. 35° W.—	15
N. 40° W.—	1
N. 45° W.—	9
N. 50° W.—	3
N. 55° W.—	11
N. 60° W.—	7
N. 65° W.—	2
N. 70° W.—	4
N. 75° W.—	21
N. 80° W.—	6
N. 85° W.—	10

Joint.	No.
N. 0° E.—	1
N. 2° E.—	1
N. 5° E.—	8
N. 7° E.—	1
N. 10° E.—	3
N. 12° E.—	1
N. 20° E.—	4
N. 25° E.—	2
N. 30° E.—	4
N. 32° E.—	2
N. 35° E.—	16
N. 40° E.—	6
N. 42° E.—	1
N. 45° E.—	9
N. 50° E.—	6
N. 52° E.—	1
N. 55° E.—	3
N. 60° E.—	7
N. 65° E.—	9
N. 70° E.—	5
N. 75° E.—	6
N. 80° E.—	7
N. 85° E.—	5
N. 90° E.—	8

Other Districts.—The other areas studied were those around Milwaukee, Madison, Devils Lake, Galena, Mineral Point, and Iron Ridge. The joint directions from the Milwaukee area were taken in three formations, the Niagara, the Helderberg, and the Hamilton; but those of the Helderberg are so poor and unreliable that they have not been entered in the summary. Those of the Niagara and Hamilton were obtained from the quarries. In the area about Madison the joints measured were in the Lower Magnesian and Potsdam formations, and were likewise obtained from quarries. In the Devils Lake area they were obtained from the quartzite cliffs. It is worthy of note that here the joints were also vertical or nearly so without reference to the dip of the bedding. At Galena the joint directions were taken from the Galena limestone, while at Mineral Point they were obtained from the Trenton and underlying St. Peter. The data at Iron Ridge were taken from the Niagara. Below are given the summaries for the different districts.

MILWAUKEE AREA.

Joint.	No.	Joint.	No.
N. 22° W.—	1	N. 5° E.—	1
N. 32° W.—	1	N. 20° E.—	2
N. 35° W.—	2	N. 30° E.—	1
N. 40° W.—	2	N. 35° E.—	11
N. 45° W.—	12	N. 45° E.—	1
N. 49° W.—	2	N. 50° E.—	9
N. 52° W.—	1	N. 58° E.—	2
N. 55° W.—	10	N. 65° E.—	4
N. 72° W.—	3	N. 78° E.—	1
N. 75° W.—	12	N. 85° E.—	1
N. 85° W.—	2		

MADISON AREA.

Joint.	No.	Joint.	No.
N. 22° W.—	3	N. 5° E.—	1
N. 32° W.—	2	N. 15° E.—	2
N. 40° W.—	2	N. 35° E.—	4
N. 45° W.—	4	N. 45° E.—	1
N. 55° W.—	1	N. 50° E.—	1
N. 65° W.—	1	N. 55° E.—	5
N. 70° W.—	3	N. 60° E.—	2
N. 75° W.—	3	N. 70° E.—	1
N. 85° W.—	3	N. 72° E.—	1
		N. 85° E.—	1

DEVILS LAKE AREA.

Joint.	No.
N. 25° W.—	2
N. 35° W.—	18
N. 45° W.—	1
N. 55° W.—	4
N. 65° W.—	5
N. 85° W.—	3

Joint.	No.
N. 24° E.—	2
N. 38° E.—	6
N. 45° E.—	2
N. 52° E.—	1
N. 55° E.—	1
N. 80° E.—	1

GALENA AREA.

Joint.	No.
N. 5° E.—	4
N. 85° E.—	5
N. 35° E.—	1

MINERAL POINT AREA.

Joint.	No.
N. 12° W.—	2
N. 25° W.—	3
N. 32° D.—	3
N. 72° W.—	2
N. 85° W.—	3

Joint.	No.
N. 5° E.—	1
N. 35° E.—	7
N. 65° E.—	7
N. 75° E.—	1
N. 85° E.—	1
N. 90° E.—	1

IRON RIDGE AREA.

N. 50° W.—	2
N. 55° W.—	3
N. 60° W.—	2

N. 12° E.—	2
N. 15° E.—	2
N. 70° E.—	2

Summary: Dominant Joint Directions of Southern Wisconsin.
 —The summary of the joint directions of the three main districts shows the noteworthy dominance of some directions over others. One of the objections to the more precise theories on jointing is the fact that joints are found trending in so many directions. This is true in a measure, but still the fact remains that there are certain prominent directions into which almost nine-tenths of the joints fall. The minor directions may in many cases be due to turns in some of the major joints, examples of which were found in the Niagara and other formations. These turns are perhaps due to local irregularities either of the rock or of the forces causing the fracture. Nothing could be farther from the truth than the view that joints are promiscuous cracks wandering irregularly through the rocks. They are definitely oriented frac-

tures which have a constant relation to one another. A careful examination of the foregoing data will reveal the fact that the joint directions are not accidental, but that there is a strong tendency for the prominent joints to be arranged in sets at right angles, or nearly so, to each other. This is shown to a very marked degree in case of the N 35° E, and N 55° W, N 35° W and N 55° E, N 5° E and N 85° W, and N 45° E and N 45° W lines.

The most prominent joints of the Prairie du Chien district are N 25° W, N 35° W, N 55° W, N 75° W, N 85° and 90° W, N 35° E, N 55° E. The less prominent ones are N 65° W, N 45° E, and N 75° E. The most prominent joints of the Richland Center District are N 36° E, N 55° W, N 5° E, N 35° E, N 45° E, N 75° E, and N 85° and 90°. Those which are less prominent here are N 15° W, N 25° W, N 45° W, and N 60° W, while N 65° W, N 75° W, N 25° E, N 55° E, and N 65° E. Those which are most prominent in the Potosi district are N 35° W, N 55° W, N 75° W, N 85° W, and N 35° E, while N 20° W, N 45° W, N 5° W, N 45° E, N 65° E, N 80° E, and N 90° E, are less prominent. This summary shows at a glance the great similarity between the prominent joint directions in the different areas.

The following table is a summary of all the joints found in the three main districts. Data were taken at about two hundred different localities and the figure after each joint shows the number of localities in which it was found.

Joint.	No.	Joint.	No.
N. 5° W.—11		N. 0° E.—18	
N. 10° W.—6		N. 2° E.—2	
N. 12° W.—2		N. 5° E.—41	
N. 15° W.—28		N. 8° E.—3	
N. 20° W.—13		N. 10° E.—4	
N. 22° W.—1		N. 15° E.—8	
N. 25° W.—59		N. 20° E.—14	
N. 28° W.—11		N. 22° E.—2	
N. 30° W.—11		N. 25° E.—29	
N. 32° W.—5		N. 28° E.—4	
N. 35° W.—67		N. 30° E.—11	
N. 40° W.—6		N. 32° E.—5	
N. 42° W.—7		N. 35° E.—71	

N. 45° W.—37	N. 40° E.—11
N. 48° W.— 1	N. 42° E.— 3
N. 50° W.— 8	N. 45° E.—54
N. 52° W.— 1	N. 46° E.— 2
N. 55° W.—65	N. 50° E.—32
N. 58° W.— 3	N. 46° E.— 2
N. 60° W.—19	N. 50° E.—32
N. 62° W.— 3	N. 52° E.— 6
N. 65° W.—31	N. 55° E.—43
N. 68° W.— 6	N. 58° E.— 2
N. 70° W.— 6	N. 60° E.—17
N. 72° W.— 7	N. 62° E.— 4
N. 75° W.—64	N. 65° E.—37
N. 80° W.—11	N. 68° E.— 3
N. 82° W.— 5	N. 70° E.—17
N. 85° W.—37	N. 72° E.—10
N. 87° W.— 3	N. 75° E.—52
	N. 78° E.— 1
	N. 80° E.—14
	N. 82° E.— 2
	N. 85° E.—33
	N. 90° E.—33

From this table we see that the prominent joints of the three districts may be put in the following order: N 35° E, N 35° W, N 85° and 90° E, N 55° E, N 75° W, N 25° W, N 45° E, N 75° E, N 55° E, N 5° E, N 85° W.

STUDY OF JOINT INTERVALS.

In addition to the orientation of joint planes, treated above, there is found in most exposures of sufficient size a definiteness of interval between successive joints trending in the same direction. More than this, there seems to be in many cases an arrangement of smaller unit intervals¹¹ into larger ones, also of a definite size and probably composed of the same number or nearly the same number of joint intervals. This tendency is very marked in many of the large sandstone exposures and also in the weathered limestone outcrops, but was less marked in fresh exposures.

¹¹This term is used arbitrarily to indicate the smallest interval which can be conveniently measured. Op. 21st Ann. Rep. U. S. G. S. Pt. 3, p. 104.

The following data were taken on the intervals between different joints in the same series. Most of them are from the Potosi area, but the locations from which they were obtained are widely scattered. (Plates IV and V.)

JOINT INTERVALS FROM THE GALENA LIMESTONE.

Joint.	Interval.	Number of intervals measured.
N. 0° E.	9 ft.	4
N. 5° E.	5 ft.	3
N. 5° E.	9 ft.	2
N. 20° E.	18. ft.	2
N. 35° E.	8 & 16 ft.	4
N. 35° E.	9 ft.	3
N. 45° E.	9 ft.	3
N. 40° E.	5½ ft.	2
N. 85° E.	6 ft.	3
N. 20° W.	12 & 25 ft.	5
N. 55° W.	9 ft.	3
N. 75° W.	9 & 18 ft.	4

INTERVALS IN THE ST. PETER SANDSTONE.

N. 50° E.	13 ft.	7
N. 55° W.	24 ft.	6

The foregoing intervals from the Galena limestone seem to be of three sizes, the first being about five feet in length, the second about twice that or nine feet in length, and the third about four times the length of the first or about eighteen feet in length. Here, therefore, is shown a rough regularity of intervals in the same formation over a large area. With better facilities of measuring very much better results would probably have been obtained.

PART II.

THE DRAINAGE SYSTEM.

EVIDENCES IN OTHER REGIONS OF THE CONTROL OF DRAINAGE BY
FRACTURE LINES.

The effect which lines of fracture have had on the drainage was seen and investigated a long time ago by Daubrée¹¹ and to a lesser extent by D'Omalius D'Halloy.¹² Daubrée investigated many areas of northern France and Switzerland and found in numerous instances a close agreement between fracture and drainage lines. He shows by his work that it is not faults exclusively which produce these results, but that joints alone may have the same effect. He assumed that joints were gaping where streams followed them, and closed where they deviated.

Research work on the subject has been done in this country by Professor Kemp of Columbia University, by Professor Hobbs of the University of Wisconsin, and Professor Iddings of the University of Chicago. Professor Hobbs has investigated the relations of the drainage of Connecticut to the fractures of that region and finds a very close correspondence between them throughout the entire state. He has also carried this outside of the state and has investigated other areas on the Atlantic slope. Dr. Hobbs differs from Daubrée in believing that joints do not have to be gaping in order that streams may follow them. His view is that joints are capillary openings in which water accumulates and by freezing and by chemical action brings about weathering and disintegration. This will produce softer layers on

¹¹Daubrée—*Géologie Experimentale*. Paris, 1879; pp. 352-373.

¹²D'Omalius D'Halloy—*Précis Elementaire de Géologie*. 8th ed. 1868; pp. 449-453.

each side of the joint which are easily eroded. Deviations from a straight course are believed by him to be often due to other joint planes crossing the first. Professor Iddings has done some work along this line in the region of Yellowstone Park and here also he finds a relation between the lines of fracture and the drainage.

CHARACTERISTICS OF THE DRAINAGE NETWORK IN THE DIFFERENT DISTRICTS STUDIED. (PLATES I, II, III.)

The streams of the driftless area either empty directly into the Mississippi or flow into the Rock or Wisconsin. In the Prairie du Chien district the drainage is toward the Mississippi and Wisconsin rivers. The Iowa streams flow directly into the Mississippi while part of the streams on the Wisconsin side flow into the Wisconsin river. On the latter side there are two large divides, both starting from the mouth of the Wisconsin. The one trends about N 30° E and the other about N 65° W. East and north of these divides the streams flow into the Wisconsin while the rest of the area drains directly into the Mississippi.

All the streams east of the Mississippi and north of the Wisconsin have a characteristic east and west direction. This is true not only of those flowing into the Mississippi but also of those which flow east into the Kickapoo river, a branch of the Wisconsin. South of the Wisconsin the direction of streams is dominantly NE-SW. On the Iowa side there is no great regularity of drainage lines. The courses of the streams here are not straight, as they are on the Wisconsin side, but irregular and winding, due perhaps to the encroaching glacial out wash. The dominant drainage direction, however, seems to be a little north of west.

The Mississippi itself occupies an extremely level valley from a mile to two miles in width, lined on either side by high bluffs. In this valley it meanders back and forth with great irregularity, producing ox-bow lakes, mud islands, and other characteristic forms. While the river itself is very irregular, the bluff line is generally straight and continuous.

The valley of the Wisconsin is similar to that of the Mississippi but the streams are less irregular and winding.

In the Richland Center area the drainage is more unified than in the preceding district. All the streams flow into the same master stream and have the same characteristic structure in all parts of the area. The Wisconsin valley here has the same form that it had in the Prairie du Chien area but is about four or five times as wide. The larger part of the bluff line here runs directly east and west. The valleys of the other streams of the district are considerably wider than those of the other two areas, and are so sandy that many of the side streams disappear before joining the main branches. For the summer months there is no running water in many of these side branches. The streams have smoothly winding courses, for the most part, with few irregularities.

The dominant directions in the drainage network of this district are N NE-S SW, E-W, N-S, and NW-SE. The Wisconsin river bluff-line, as has been stated, trends prominently east and west. In the eastern part of the district, however, the southern bluffs swing around to a W NW-E SE direction. Pine river has a north and south direction in its lower course. It then takes a NW-SE direction until it reaches a point about a mile south of Richland Center when it resumes its north and south course. Later it trends N NE-S SW, while its upper course is again north and south. Big Bear creek also has a north and south direction at its lower course which changes to a N NE-S SW direction in its main course while near its head waters it flows directly south. Little Bear creek in its lower course flows directly west, but later has the same N NE-S SW direction as the Big Bear. Willow Creek follows the same north and south line that the Pine river had in its lower course. Fancy creek and the west branch of the Pine have prominent NW-SE courses. Otter creek trends N NE-S SW for about eight miles of its lower course and then changes gradually to an east and west direction. Sneed creek flows northwest, while Underwood creek flows directly north. These rivers include nine-tenths of the prominent streams of the area and the courses of all of them fall into the four main directions before mentioned.

In the Potosi district the valleys are narrow and steep sided with few evidences of flood plains. The streams of the entire

areas have irregular winding courses. These, however, are not meanders in a flood plain, for the flood plain is absent and the bluffs follow all the curves. This is unusual for streams under normal conditions of erosion, and some other forces must have been present to alter those conditions. Whatever these forces may have been it is safe to take the main directions of the streams in discussing their orientation and neglect minor curves and irregularities.

The Big Platte river has a general north and south direction. The direction of the Little Platte is east and west in its lower course and becomes N NE-S SW in as it nears its headwaters. The main stream of the Grant river has a NW-SE direction while its large side branch flows south south west. The Little Maquoketa river has a lower east and west course while its upper course is almost parallel to that of the Grant.

From the above discussion we see that the rivers of all three areas follow a few definite directions. Below we shall see how these correspond with the chief directions of jointing.

RELATION BETWEEN THE JOINT SYSTEM AND THE DRAINAGE NETWORK.

Evidences seen on Maps.— In the preceding section we have seen that there is a definitely oriented network of drainage lines in the different districts and that the orientation is confined to a few main directions. We shall now see that the prominent directions of jointing correspond with the prominent drainage directions. (Plates I, II, III.)

In the Prairie du Chien area there is a very evident relation between joint and drainage lines, especially in the region of the east and west streams. It may be seen from the map that of the joints in this region by far the most numerous and prominent are those trending approximately east and west. South of the Wisconsin the prominent east and west joints are absent, being replaced by joints whose directions are between N 35° and 55° E. This absence is clearly connected with the absence of east and west drainage lines, these being replaced by streams trending approximately NE-SW. West of the Mississippi the north and south line is fairly prominent, and a number of small

streams, besides the west bluff of the Mississippi take this direction. Bloody Run in its general direction corresponds very well with the east and west lines near it, and many other minor coincidences may be noticed in looking over the map.

In the Richland Center region the main directions of the rivers have already been given as N NE-S SW, ($N 35^{\circ} E$); N-S, ($S 5^{\circ} E$); NW-SE ($N 55^{\circ} W$); and E-W ($N 85^{\circ}-90^{\circ} E$ and W). By referring to the summary of joint directions in this district, it will be seen that the main joints correspond with the main rivers in their trend. While this is true of the area as a whole, striking individual coincidences may be seen in all parts of the map. The Big and Little Bear both correspond with the prominent joints in the vicinity (11 and 14 of Plate III). The bluffs of the Pine river correspond closely with the prominent north and south line near it (13), while Ash creek has the direction of the W NW joint in 12. The headwaters of the Pine correspond in direction with the north and south joint in 3, while its west branch has the same trend as the $N 55^{\circ} W$ joint in the vicinity. South of the Wisconsin we have Otter creek flowing in a $N 35^{\circ} W$ direction, which joint is seen in both 19 and 16. There are probably many other examples in parts of the area where data on joint directions have not been collected, but the preceding covers very well the area studied.

In the Potosi area the direction of the main courses of the streams (ignoring the minor curves and irregularities previously mentioned) also show the control by dominant joints. The Big Platte river corresponds very well in direction with the north and south line along its course. Grant river has the same direction as the $N 35^{\circ} W$ in 4 (Plate I), while its north branch has approximately the same direction as the joint $N 35^{\circ} E$ in 1 and 4. The main upper course of the Grant and the other prominent rivers of the district are in regions where few or no data on joint directions have been taken.

Evidences seen in the Field.—After this discussion of the evidences of control of drainage by joints as shown on the map it may be well to turn to the field evidences. These are abundant especially in the smaller streams where outcrops are numerous. An observer might walk up the rocky beds of any of the abundant

minor streams and he will find case after case where the streams follow joint plains. In the sandstone the rocks on both sides of the joint have been removed, causing a little depression along the bottom where the joint may be seen to run. These little depressions may be a foot deep and may run for a long distance. (Plates VI, VII & VIII.) In the limestones this gouging out along joints does not take place, but in many cases we see joints following the beds of the streams. In other cases we see vertical walls of limestone running along the bank of the stream and following its course. Very often another wall will intersect this one at some angle and then the stream will follow the new course. (Plates IX and X.) This taking up of a new course is also true in the sandstone, for in many cases we find the depression following first one, then another joint. One of these, however, is generally more prominent than the others and is therefore apt to control the direction of the stream.

SUMMARY AND CONCLUSIONS.

From the foregoing discussion it seems very evident that the drainage directions of southwestern Wisconsin are to a large extent controlled by joint plains. There are in the three districts studied, a few dominant directions followed by joints and streams alike. Since these directions prevail in selected areas in different parts of the district we may fairly assume that they are dominant throughout the region. As has been shown, the drainage in the two northern districts has a very distinct orientation, and a close relation exists between the jointing and the drainage directions. In the southern district these directions are more or less obscured by minor irregularities, but after some study it becomes apparent that even here the general direction of streams conforms to prominent joint directions.

From the foregoing treatment we may draw the conclusion that under conditions which have prevailed in southwestern Wisconsin the drainage is to a very large extent influenced by joints and other planes of fracture. It may not be exclusively controlled by them; many other forces may have been present to modify the result, yet this same result shows how small the influence of the latter has been.

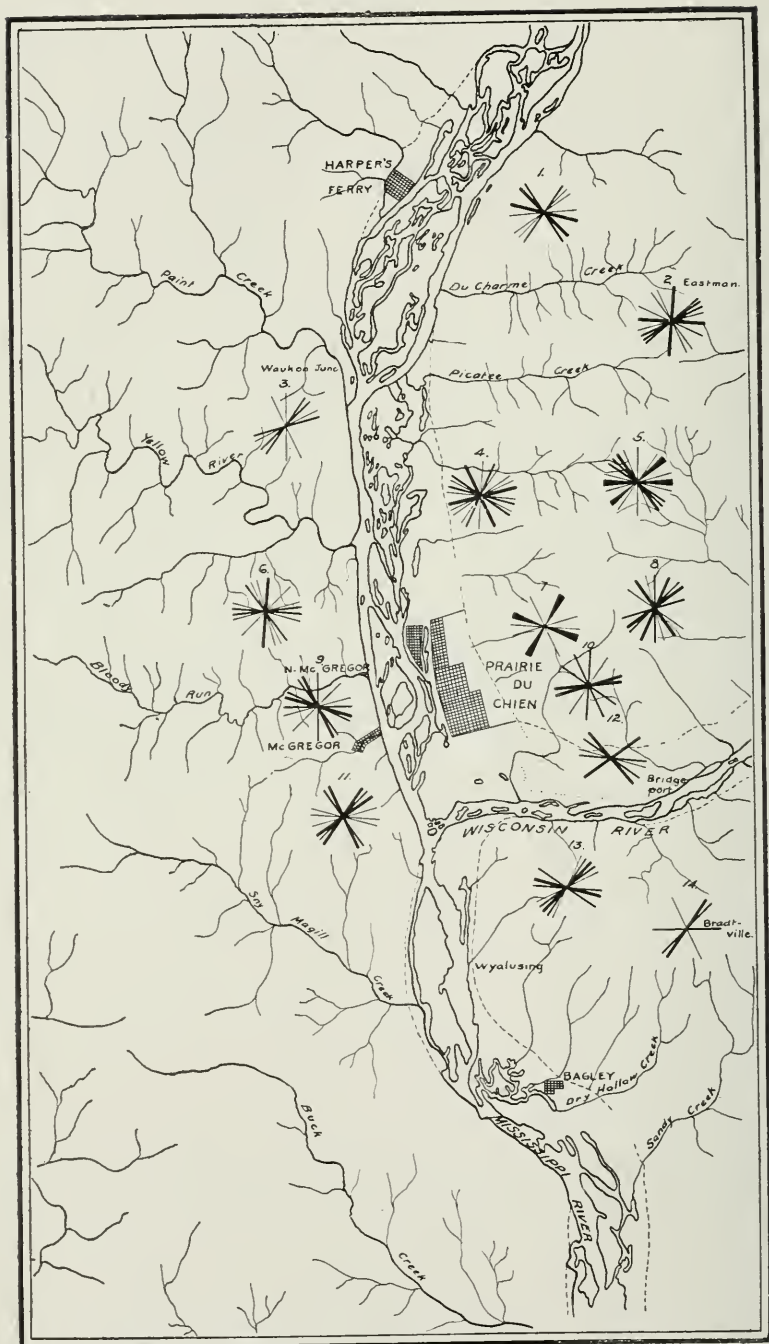
Further work along these different lines is very essential. Investigations should be carried on in different regions to see how the degree of control varies under different conditions of aridity, humidity, or high and low altitudes. But more important than this is the further study of joint intervals, which has here been merely touched upon. Very interesting results should be brought out by further investigation along these lines.

PLATE I.



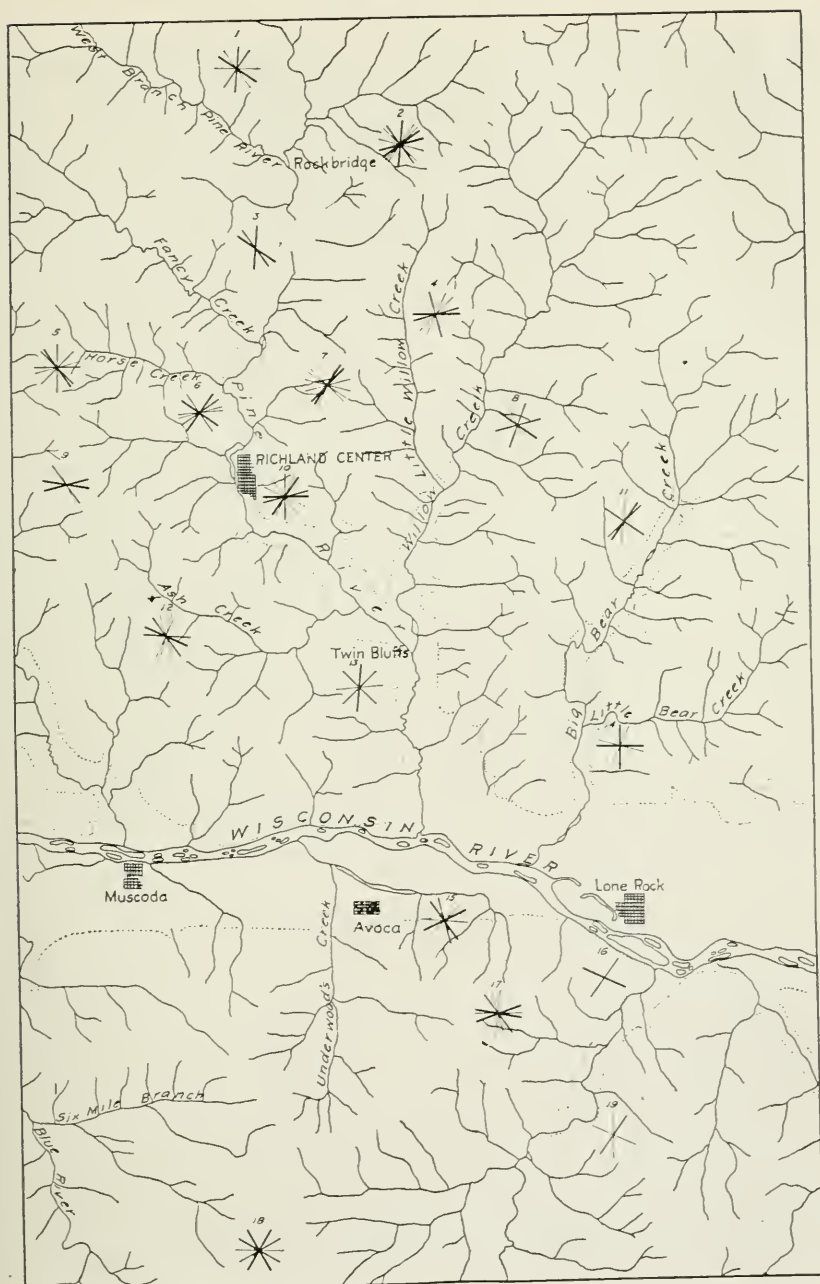
Joint and drainage map of the Potosi District. The dotted lines represent bluffs, and the stars indicate the local importance of joint series. Scale, 1 inch = $3\frac{1}{2}$ miles.

PLATE II.



Joint and drainage map of the Prairie du Chien District. The dotted lines indicate the bluffs and the stars indicate the local importance of joint series. Scale, 1 inch = 4 miles.

PLATE III.



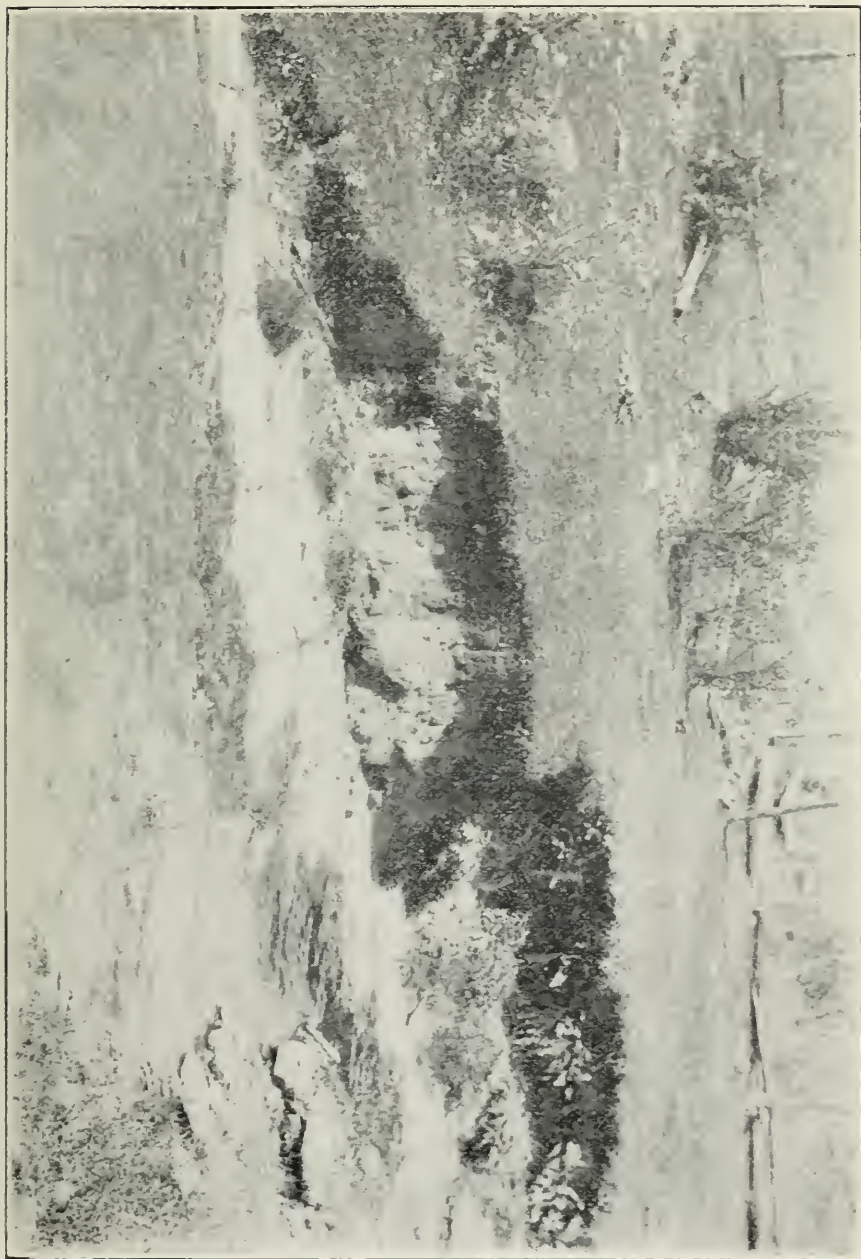
Joint and drainage map of the Richland Center District in southwestern Wisconsin. The dotted lines represent bluffs, and the stars indicate the local importance of joint series. Scale, 1 inch = 5 miles.

PLATE IV.



Joint Intervals in the "Quarry Reds," one mile east of Prairie du Chien.

PLATE V.



Joint intervals in the Trenton limestone, two miles west of Bradville.

PLATE VI.



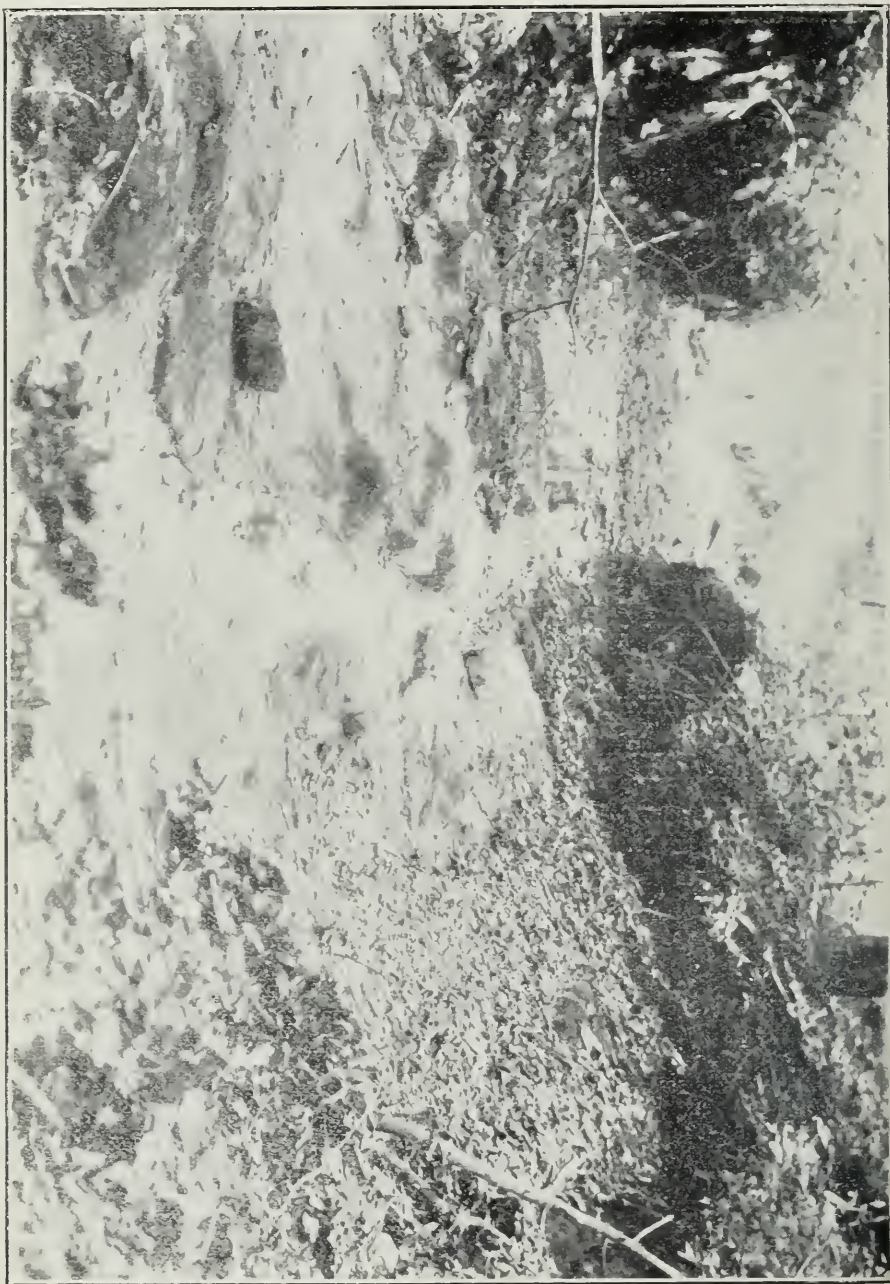
Stream following a joint in St. Peter sandstone, two miles northwest of Prairie du Chien.

PLATE VII.



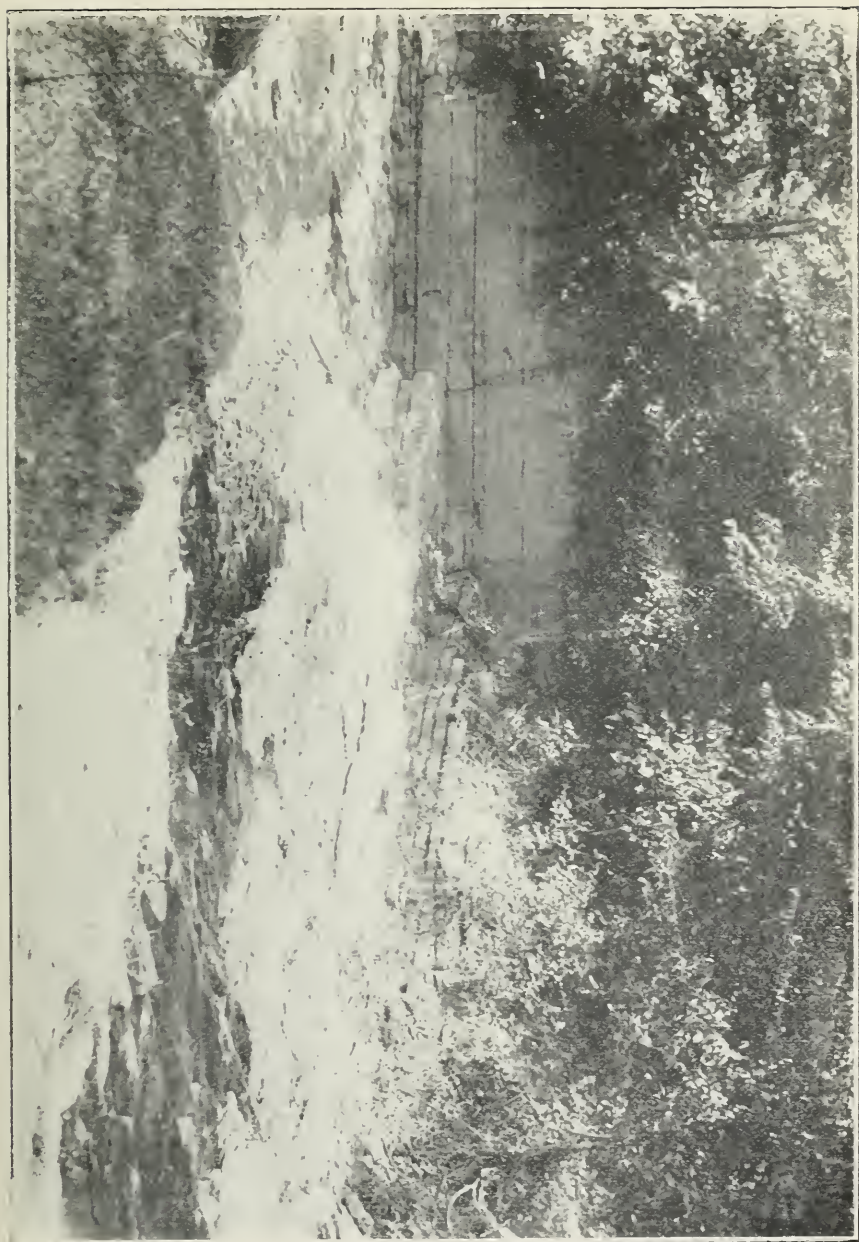
Stream following a joint in St. Peter sandstone, two miles northeast of Prairie du Chien.

PLATE VIII.



Stream following joints in St. Peter sandstone, one and one-half miles southwest of Bridgeport.

PLATE IX.

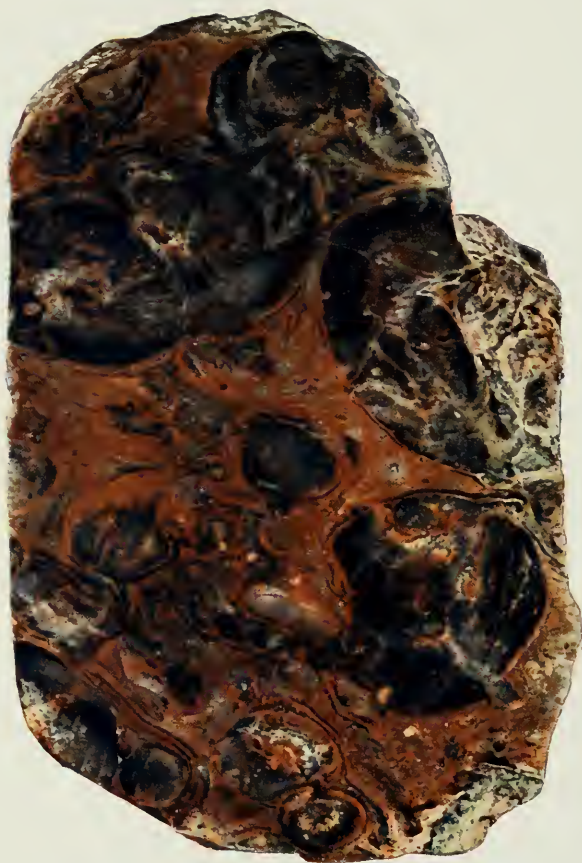


Stream following joints in Trenton limestone, two and one-half miles west of Bradville.

PLATE X.



Stream following joints in Trenton limestone, three miles northeast of Prairie du Chien.



POLISHED SURFACE OF SPHERULITIC APORHYOLITE
FROM MARCELLON DISTRICT.

2-17
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THE PRE-CAMBRIAN VOLCANIC AND INTRUSIVE
ROCKS OF THE FOX RIVER VALLEY
WISCONSIN

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THE PRE-CAMBRIAN VOLCANIC AND INTRUSIVE ROCKS OF THE FOX RIVER VALLEY, WISCONSIN

I.

NATURE, DISTRIBUTION AND AGE OF THE IGNEOUS ROCKS.

Within the Potsdam sandstone and later Paleozoic formations of the valley of the Fox River in south central Wisconsin are found a number of small isolated areas of pre-Cambrian crystalline rocks of igneous origin, whose distribution is indicated in Figures 1 and 2.

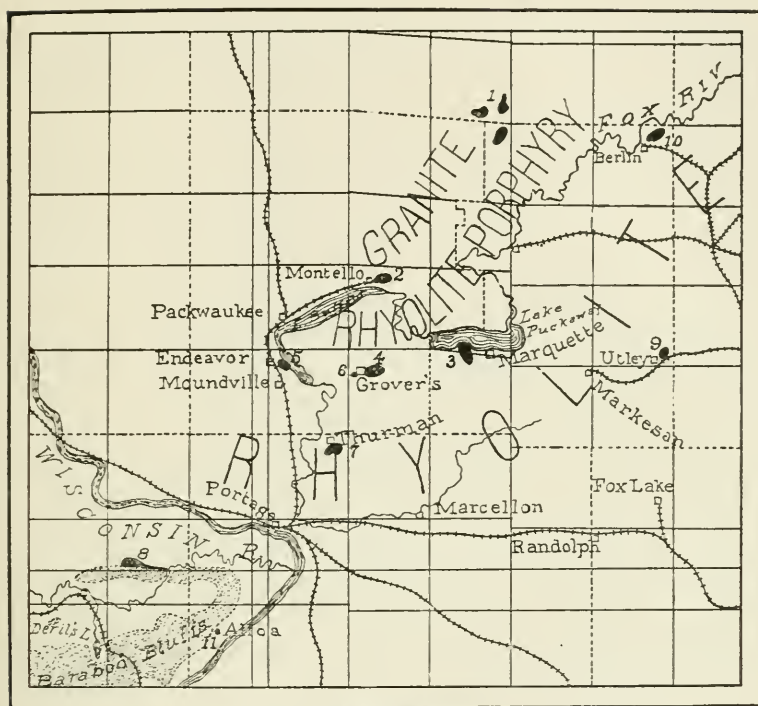
They lie in an area some sixty miles in length and twenty-five in breadth. The nearest approach of the great pre-Cambrian area of the state to the rocks here under consideration is at the town of Waupaca, about 15 miles to the north of the northernmost of the outliers in Waushara county. Only one of the knobs of crystalline rock much exceeds a square mile in area, and most of them are very much smaller. All have been smoothed and rounded by glaciation, and now stand bare and open to study, in most cases well above the level of the surrounding sedimentary rocks. In places they rise from the level of the sedimentary rocks in sharp cliffs. On the west flank of Observatory Hill, where these cliffs are seen to best advantage, large well rounded pebbles, up to eight inches in diameter, such as might today be picked up on the coast of Massachusetts, readily separate from the friable Potsdam sandstone near its contact with the porphyry.



Fig. 1.—Map of Wisconsin showing location of Fox River district.

The pebbles dwindle in size as they are found farther from the contact, and at a distance of a few yards the sandstone is quite free from them.

The principal rock of the areas is of fairly uniform chemical and mineralogical composition, but varies widely in texture, according to which variation it has been named in different areas, granite, quartz keratophyre, soda-aporhyolite, metarhyolite, rhyolite-gneiss, etc. Perhaps nowhere else have such ancient rocks been described where the evidences of the peculiarly complex crystallizations of surface volcanic rocks have been so well preserved. In nearly all of the areas the acid rock is cut by dikes of a considerably altered andesite porphyry and later rhyolite.



Huronian Quartzite. Archean (?) Igneous. Paleozoic Sediments.
Rocks.

Fig. 2.—Sketch map of the petrographic province of the Fox River Valley, Wisconsin. Areas of granite are located in Waushara county and at Montello. Quartz keratophyre occupies areas in Waushara county, at Marquette, and at Observatory Hill. Soda aporhyolite in some of its phases is found at Endeavor, Taylor's Farm (near Grover's Postoffice), in Marcellon (near Thurman Postoffice), in the Baraboo Bluffs, at Utley, and at Berlin.

The markedly close relationships of the Fox River Valley igneous rocks in chemical composition are presumptive though not conclusive evidence of similarity of geological age. That this is pre-Cambrian is obvious from the relations just described. Weidman's conclusion that the igneous rocks of the Baraboo region are older than the Baraboo quartzite probably applies to the other areas of pre-Cambrian rocks in the Fox River Valley. All are therefore classed provisionally as Archean.

The Fox River crystalline rocks were mapped and briefly described by the geologists of the early Wisconsin Geological

Survey.¹ Their igneous origin was not distinctly recognized, and indeed, from the stress which was laid upon the strike and dip observations, it is evident that some of the geologists of the Survey held the belief, common at the time, that such rocks were of sedimentary origin.

Weidman, in 1893, published a description of the quartz keratophyre of the north Baraboo range,² and in 1898 he published an adequate discussion of the Berlin and Utley igneous rocks.³ Still later the discovery of iron ore in the Baraboo range led Weidman to make a careful study of the Baraboo district. Some of the results of this study were the discovery of new areas of crystalline rock at the Markert Farm near Denzer, where the rock is rhyolite and at Myer's Mill on Otter Creek, where granite and its sheared phases are found.⁴

The field work upon which the present report is based was commenced by the senior author in 1894 when he directed the preparation of a thesis on the Marquette area by Mr. W. W. Pretts and made a general examination of the other areas. The detailed mapping of Observatory Hill, Marcellon, Moundville, and Taylor's Farm was done by the authors jointly in 1896. During and subsequent to the detailed mapping, a number of general examinations of the district have been made by both authors. Papers treating of the structure and composition of the rocks of the district have from time to time been presented before the Geological Society of America.⁵

The authors are indebted to the Regents of the University for financial assistance in field work and in preparing thin sections of the specimens collected, and to the Wisconsin Geological

¹ Annual Report of the Geological Survey of Wisconsin, by James G. Percival, 1856, pp. 104-107.

Geology of central Wisconsin, by R. D. Irving. Geol. of Wis. Vol. II, part 3, 1877, pp. 501-524.

Geology of eastern Wisconsin, by T. C. Chamberlain. Ibid. pp. 248-252.

² On the quartz keratophyre and associated rocks of the north range of the Baraboo bluffs, by Samuel Weidman. Bull. Univ. of Wis., Science ser., vol. 1, 1895, pp. 35-56.

³ A contribution to the geology of the pre-Cambrian igneous rocks of the Fox River Valley, Wisconsin, by Samuel Weidman. Bull. Wis. Geol. & Nat. Hist. Survey, No. III, Sci. ser., No. 2, 1898, pp. 1-63.

⁴ The Baraboo iron-bearing district of Wisconsin, by Samuel Weidman. Bull. Wis. Geol. & Nat. Hist. Survey, No. XIII, Econ. Ser. No. 8, 1904, pp. 12-21.

⁵ Bull. Geol. Soc. Am., vol. 7, 1896, p. 7, and vol. 11, 1900, p. 5.

and Natural History Survey for chemical analyses. Acknowledgement is made to Mr. W. W. Pretts for material drawn from his thesis on the Marquette area. The authors are also indebted to Mr. Geo. E. Knowles, of the Berlin and Montello Granite Company, who, without charge, kindly prepared a considerable number of polished specimens at the polishing plant of the Berlin and Montello Granite Company.

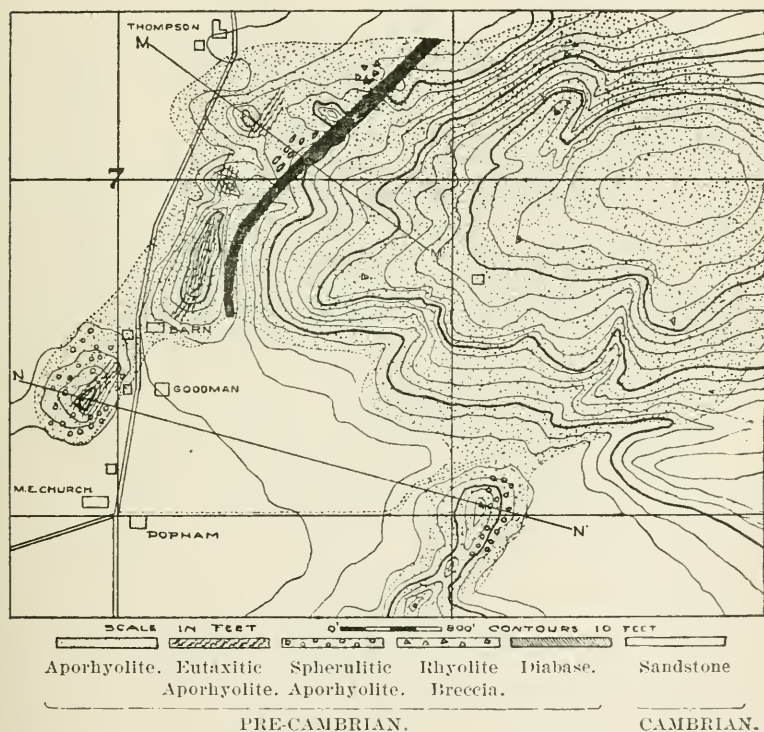


Fig. 3.—Map of the Marcellon area, by W. H. Hobbs and C. K. Leith.

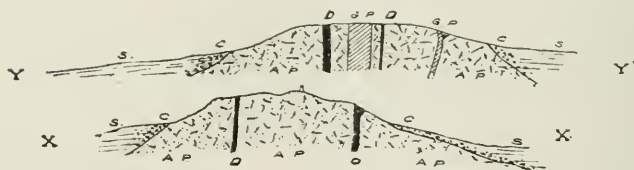
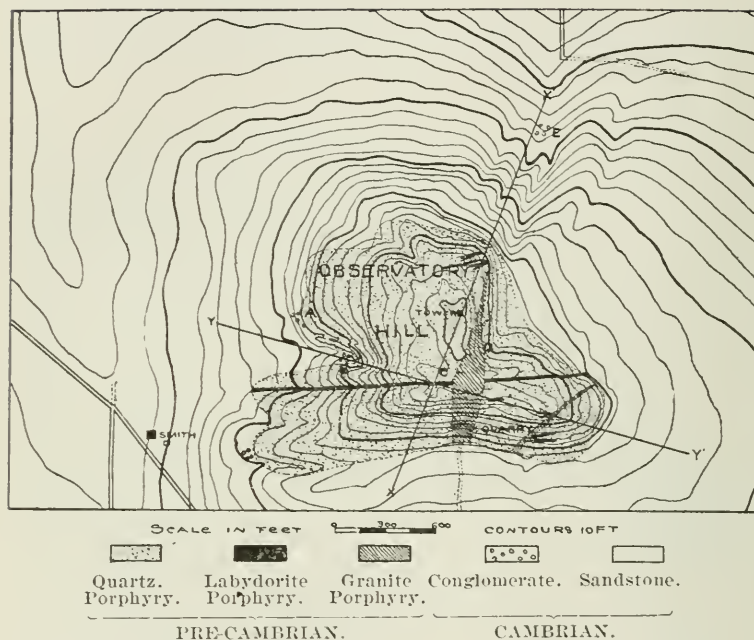


Fig. 4.—Map of Observatory Hill area, by W. H. Hobbs.

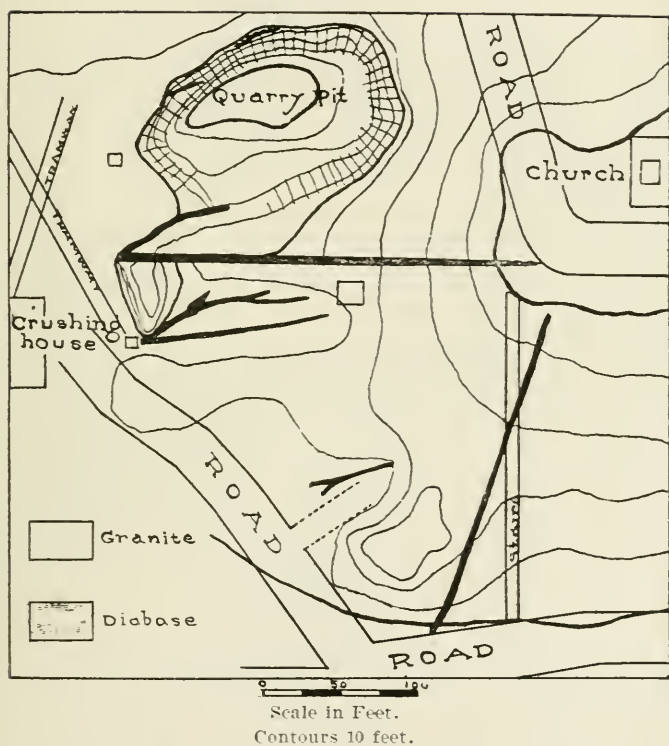


Fig. 5.—Map of Montello quarry area, by W. H. Hobbs.

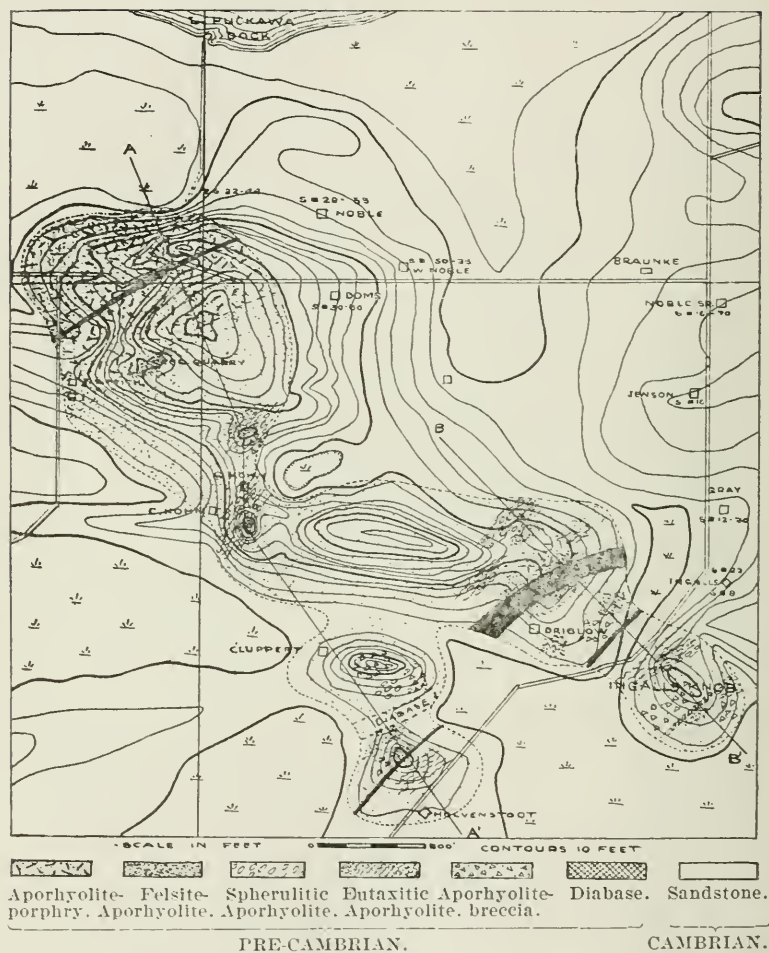


Fig. 6.—Map of Marquette area, by W. H. Hobbs and W. W. Pretts.

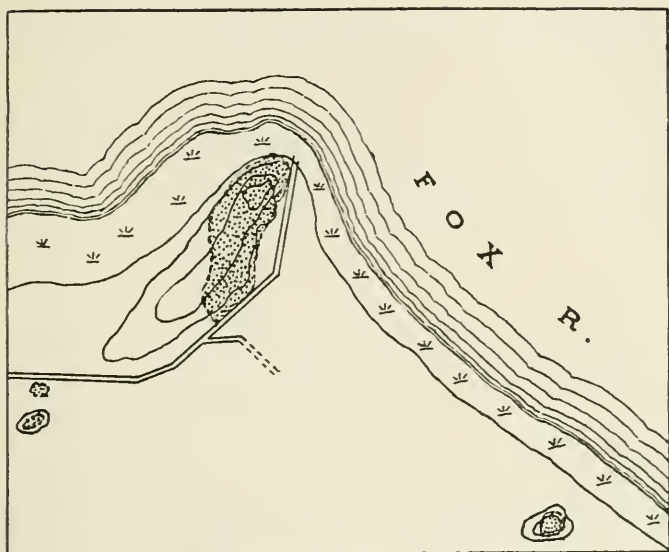


Fig. 7.—Map of Endeavor area, by C. K. Leith.

II.

CHEMICAL COMPOSITION OF THE IGNEOUS ROCKS.

Complete analyses have been made of the volcanic rocks of the Fox River Valley upon fifteen samples representing occurrences well distributed in the district. Three of these (those from Baraboo, Berlin and Utley) have been already published by Weidman.⁶ The remaining ones have been made especially for this investigation by Professor W. W. Daniells in the chemical laboratory of the University of Wisconsin. The results are given below, together with the formula in the quantitative classification as obtained by computation of the norms.

⁶The Igneous Rocks of the Fox River Valley, by S. Weidman. Bull. Wis. Geol. and Nat. Hist. Survey, No. III, 1898.

The close agreement of these analyses with one another is best shown by plotting them in the manner suggested by Brögger.⁷ (See Fig. 8.)

In common, the rocks of the province are characterized by high silica percentage (73% to 79%), but the most notable feature of them is the uniform predominance of soda over potash, when reckoned in molecular proportions, in every area except Montello, where the two are present in equal proportions.

MOLECULAR RATIOS OF SODIUM TO POTASSIUM OXIDES.

Western District.

Endeavor,	3.41
Baraboo,	3.63

Central District.

Marcellon,	2.66
Marquette,	1.37 and 2.06
Alloa,	1.36
Taylor's Farm,	1.28
Observatory Hill,	1.28
Waushara,	1.50
Montello,	1.

Eastern District.

Utley,	3.64
Berlin,	3.00

⁷ Die Eruptivgesteine des Kristianiagebietes. III. Das Gangefolge des Laurdalits. Kristiania, 1898; p. 255, Pl. I. See also Jour. Geol., vol. VIII, 1900, pp. 1-31, 7 p'.

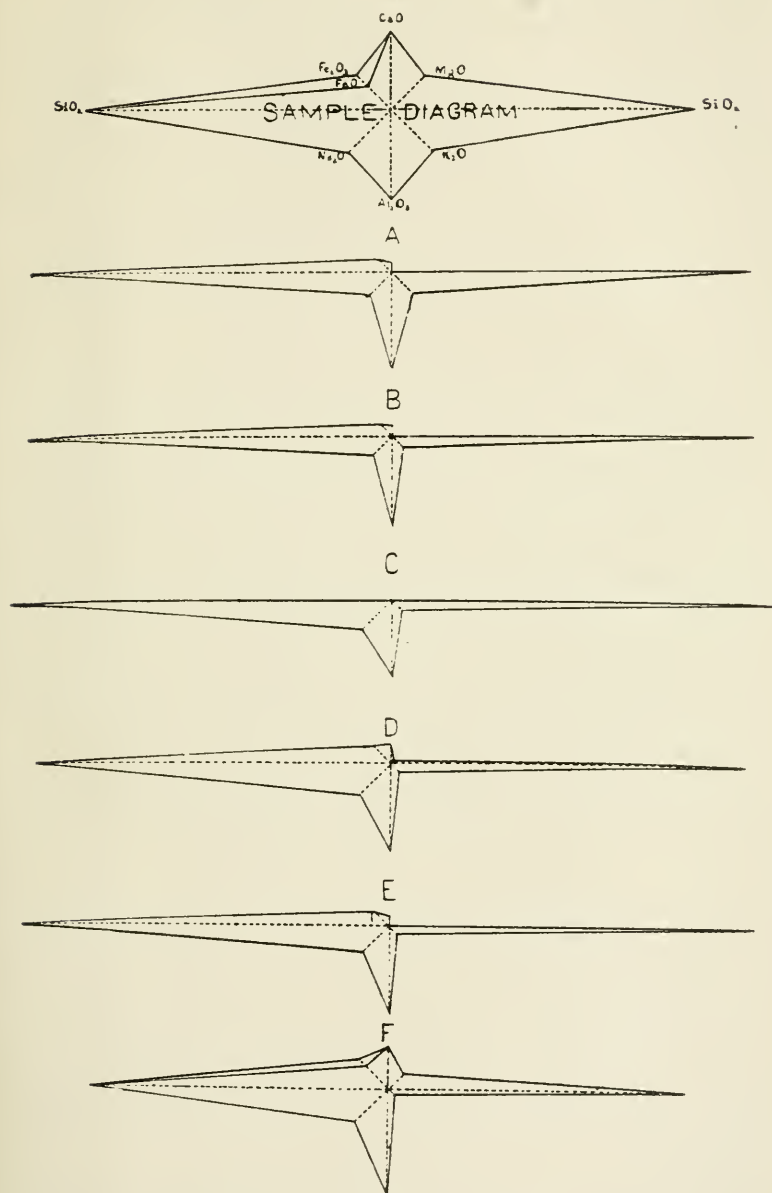


Fig. 8.—Graphic representation of the composition of the igneous rocks of the district.

- A. Quartz keratophere, Observatory Hill.
- B. Spherulitic soda aporhyolite, Marcellon.
- C. Soda felsite, Marquette.
- D. Soda granite porphyry, Observatory Hill.
- E. Granite, Montello.
- F. Andesite, Marcellon.

Interesting as are the marks of consanguinity within the Fox River province, as disclosed by these analyses, minor differences which they show between the rocks of the several areas are hardly less instructive. The rhyolite porphyries of Observatory Hill and Marquette are almost identical, their molecular proportion of soda being about one-third greater than that of potash. The granites to the north are richer in the heavy bases, but correspondingly poor in alumina, though they are otherwise almost identical with the rhyolite porphyries. In contrast with both granite and porphyry, the massive aporhyolites from the eastern and western portions of the province are much richer in soda, the average ratio of sodium oxide to potassium oxide being 3.42. The riebeckitic hornblende, which occurs in the Berlin rock, influences the analysis by an increase in the protoxide of iron, and a corresponding decrease in the alumina. In the central area (Marquette, Marcellon and Taylor's Farm), where, in the aporhyolites, the greatest differentiation of structure is to be observed, the differences in composition are more notable.

The rock of the Taylor's Farm area, which is separated from the keratophyre of Observatory Hill by only about a mile, and lies in its trend along the axis of the province, agrees closely with the keratophyre in its alkali ratios. The aporhyolites of Marcellon and Marquette, both near the keratophyre, are, in regard to their ratios of the alkalis, intermediate between the keratophyre and the aporhyolite of the eastern and western areas. On the other hand, in regard to acidity, the Marcellon and Taylor's Farm aporhyolites most resemble each other in that both have silica percentages in excess of 78, whereas the average acidity of the remaining rocks is 73.54. This is probably in part to be ascribed to secondary infiltration of silica after deformation of the rock, evidence of which is to be found in the veins of silica seen in the hand specimen. The limits in composition are, for all save the greenstone: SiO_2 79.09-71.24; Al_2O_3 17.02-10.01; Fe_2O_3 3.85-1.16; FeO , 5.44-1.18; CaO 2.78-.25; MgO 1.03-0; MnO .97-0.

The acid dike rocks, the felsite of Marquette and the granite porphyry of Observatory Hill, agree almost exactly in composition with the normal aporhyolites, the soda-potash ratio (3.52 and 2.68 respectively) being maintained.

SiO

Al₂O

Fe₂O

FeO

CaO

MgO

K₂O

Na₂O

H₂O

H₂O

CO₂

MnO

Rati

Nam

Forr

ALKALI GRANITES

SODA APOPHYLLITE PORPHYRIES

SODA APOPHYLLITES

DIEB ROCKS

Vikah Granite
Porphyry.Angite Andesite
Porphyry.

	I		II		III		IV		V		VI		VII		VIII.		IX.		X		XI.		XII		XIII		XIV.		XV.	
	Montello		Wausara		Observatory Hill		Marquette.		Marquette.		Baraboo		Endenbor.		Taylor's Farm		Marcellon.		Marquette		Albia (Breccia)		Utley		Berlin		Observatory Hill		Marcellon.	
SiO ₂	73.78	1.231	74.62	1.244	74.46	1.241	73.30	1.222	73.66	1.218	71.24	1.187	72.80	1.213	78.27	1.304	79.03	1.318	73.94	1.231	71.14	1.186	73.09	1.220	73.65	1.227	75.55	1.250	61.11	1.018
Al ₂ O ₃	17.18		16.01		15.24		15.32		15.40		12.20		15.50		11.11		13.21		16.44		18.58		13.43		11.18		14.50		10.28	
Fe ₂ O ₃			3.85		1.95		1.21		05		1.71		2.04		1.73		34		50		003		1.25		004		40		1.87	
FeO....	1.64	023	1.72	024	74	010	001	013	2.10	029	5.44	076	60	008	1.03	014	18	003	18	009	48	012			3.25	045	2.25	031	3.00	050
CaO	85	015	2.41	043	02	016	1.73	024	1.74	062	98	018	70	009	28	005	25	004	65	012	2.14	004	2.29	011	2.78	005	1.10	020	4.10	079
MgO			33	008	108	002	70	009	12	003	13	003	08	002	trace.	07	002	trace		37	005	1.03	025	51	012	03	001	1.38	035	
K ₂ O	4.48	048	3.38	036	3.01	032	3.86	041	2.01	021	1.86	019	2.52	027	4.08	043	2.28	024	3.07	033	2.02	024	1.78	017	1.86	020	2.10	023	1.07	011
Na ₂ O	2.82	046	3.33	054	2.57	041	4.47	056	4.57	074	4.20	059	5.70	092	3.44	055	3.95	064	4.23	068	2.34	004	3.85	062	3.74	064	3.74	061	4.13	073
H ₂ O at 115°			21				05		15		81		16		10		01										15			
H ₂ O at red heat	12				58		21						27		15		18		44				72		44		40		1.20	
CO ₂																					13						03			
MnO											17																			44
Total	100.87		99.91		99.70		100.10		99.85		99.64		100.10		100.05		99.72		99.85		100.90		98.56		98.73		100.71		80.74	
Ratio Na ₂ O:K ₂ O	1		1.50		1.25		1.47		1.32		3.43		3.41		1.28		2.00		2.06		1.96		3.04		1.00		2.65			
Name	Tehamose		Tehamose		Tehamose		Tehamose		Kallernulose		Alsbachose		Kallernulose		Alaskose				Kallernulose		Kivaenose		Alsbachose				Alsbachose			
Formula	I 323		I 323		I 424		I 424		I 441		I 342		I 114		I 313		I 314		I 414		I 457		I 321		I 104		I 314		II 115*	

*Reckoned as Fe₂O₃.

*No analyses of this type are included in Washington's list.

Calculation of the norms shows that the range of the acid rocks is represented by I, 3-4, 1-3, 3-4. If the published analyses afford any clue to the relative abundance of rock types, the rhyolite porphyries from Observatory Hill and Marquette (I 423) are of a much more common type than the others. The closely allied soda felsite from Marquette (I 424) is also of common occurrence. The soda aporhyolite from Marcellon and that from Berlin are a comparatively rare dosodic type (I 314) to which the authors of the quantitative classification have not assigned a name.

The augite andesite at Marcellon belongs in class II of the classification and is of a species not represented by analyses in Washington's tables.

III.

TEXTURES OF THE IGNEOUS ROCKS.

Texturally, the acid rocks of the several areas show the widest range. The Waushara rock, as described by Weidman, is a mas-



Fig. 9.—Mashed spherulites in aporhyolite from Marcellon area. Two-thirds natural size.

sive, medium-grained granite mainly composed of quartz and feldspar. At Montello is found a dense, massive granite of essentially the same mineralogical composition which is quarried extensively for monumental work and for block paving, and is now well known as the stone from which the sarcophagus of General Grant was sculptured. At Observatory Hill the rock is a massive rhyolite porphyry which does not exhibit any certain evidence of its surficial origin, although a lineal arrangement of magnetite crystals has been made out in one or two sections. Comparable with this is the rhyolite porphyry of Noble's Quarry,



Fig. 10.—Mashed spherulite groups in rhyolite of Marquette area. Two-thirds natural size.

in the Marquette area, though the quarry is separated by less than half a mile from rocks of nearly identical composition, but which exhibit rhyolitic, spherulitic, perlitic, and other surficial textures, and are associated with volcanic breccias in great abundance. It is in the Marcellon area that the textures peculiarly characteristic of acid effusive rocks are found in the

best development. In the small knob situated just west of the stage road from Portage to Montello the spherulites appear in the rock like a collection of pebbles, and individual spherulites have been found considerably larger than a man's fist. A little to the north, and on the east of the road, the smooth surface of the exposure is beautifully figured by the curling chains of spherulites (axiolites), which are crowded in the black devitrified groundmass of the rock.

In the Endeavor area the rock is found to be a remarkably massive rhyolite porphyry resembling that of Observatory Hill and Marquette, though it shows a distinct banding, or eutaxitic texture, which the microscope, by its revelation of spherulitic,



Fig. 11.—Perlitic parting in rhyolite of Marquette area as seen under the microscope.

fluxion, and poikilitic textures compels us to interpret as one of the results of flowage. The eutaxitic texture of the Marcellon rhyolite is a rhyotaxitic or fluxion texture, in that the rock shows alternating lenses or *schlieren*, which differ in texture or composition or both, ranged in the direction of flow. The prominence which this texture now has is due to devitrification and second-

any coloration, but the original lenses of the rock have governed the distribution of the secondary products.

Under the term fluxion texture is here included the alignment, in the direction of flow, either of individual minerals or of spherulites. The eutaxitic texture is noticed in the rocks showing differently colored bands and lenses. No very sharp lines can be drawn to separate the two textures. At Taylor's Farm, the rock is likewise massive and reveals to the unaided eye little evidence of surface origin. Under the microscope, however, the



Fig. 12.—Flow structure in aporhyolite from Marcellon area. Two-thirds natural size.

rhyolitic texture of the groundmass is most pronounced. The rock at Baraboo is a rhyolite, showing typical volcanic textures. The Utley rock is a massive, fine-grained rhyolite. The Berlin rock, as the result of profound mashing, is a rhyolite gneiss.

We thus find in the several areas every gradation from the granite, through a massive rhyolite porphyry into a rhyolite in which all the evidence of former flowage and rapid surface cooling is apparent. The areas of granite are contiguous and the areas of keratophyre lie in a zone bordering the granite on the

east and south, while the rhyolite areas lie in an outer zone beyond the keratophyre and farthest removed from the granite. (See Fig. 2.)

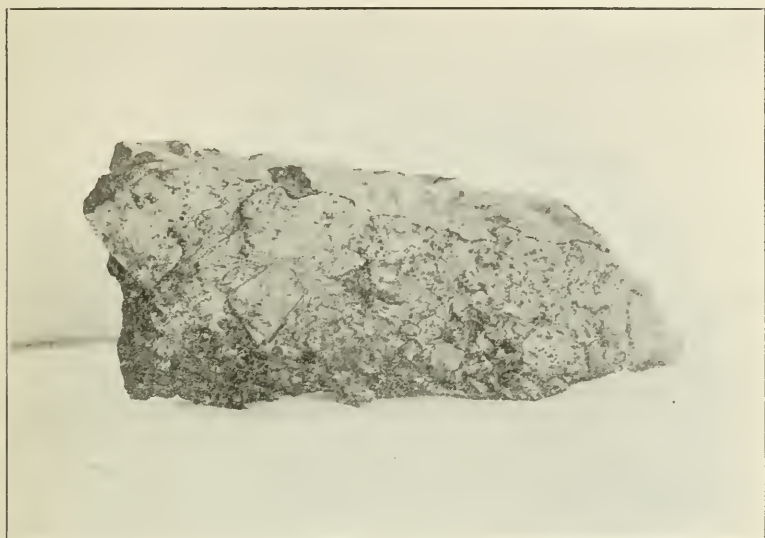


Fig. 13.—Aporhyolite breccia from Marcellon area. Two-thirds natural size.

IV.

THE SODA APORHYOLITE OF THE CENTRAL AREA AND ITS PECULIAR TEXTURES.

Detailed petrographical description of the several rock types will not be attempted within the limits of this paper. The rhyolitic lava, particularly as developed at Marcellon, presents so many interesting textures, however, that it can hardly be passed over without a brief mention of some of them.

The soda aporhyolite, though still exhibiting in unusual perfection textures which could have developed only in a vitreous lava, now shows no glassy material, the groundmass consisting always of a micro-crystalline or crypto-crystalline aggregate of quartz and feldspar, thus indicating that devitrification of an originally partially glassy base must have taken place.

As developed in the Endeavor and Taylor's Farm areas, the

soda aporhyolite is rather massive, with the common aspect of quartz porphyries and may exhibit only under the microscope the structures which are the evidences of its surficial origin.

The phenocrysts of the aporhyolite are feldspar and quartz,



Fig. 14.—Photomicrograph of fan-shaped spherulite in aporhyolite from Marcellon area.

in about equal proportions. The feldspars show some variety of forms and alterations, which will not here be discussed, but which include untwinned feldspar resembling orthoclase, microcline, and micropertthite. Some of the larger and clearer crystals were separated from the Endeavor rock and submitted to Prof. W. W. Daniells for chemical analysis. Under the microscope these feldspars are seen to be either untwinned, resembling orthoclase, or to show locally the microcline structure. The analysis follows:

SiO ₂	68.53	1.134
Al ₂ O ₃	19.62	.192
CaO	.25	.004
K ₂ O	6.73	.071
Na ₂ O	4.44	.071
	99.57	

The predominant feldspar in the Endeavor rock is therefore probably a soda orthoclase or soda microcline containing soda and potash in about equal molecular proportions.



Fig. 15.—High power view of part of spherulite shown in Fig. 14.

The groundmass is a quartz-feldspar aggregate which shows spherulitic, rhyotaxitic, and poikilitic textures. Subordinate constituents are magnetite, hematite, greenish biotite, sericite, epidote, and calcite.

The aporhyolite of the Marcellon district exhibits the peculiarities of spherulitic crystallization on a grand scale. In the knob near the Methodist Chapel the entire rock is made up of spherulites, the larger ones of which measure fully four inches in dia-



Fig. 16.—Photomicrograph of spherulite in aporhyolite from Marcellon area.

meter. Owing to a perlitic parting which follows their surfaces, these spherulites separate from the rock like large pebbles (Fig. 9). Many of them are surrounded by a thin layer of quartz and they are often crossed by seams of infiltrated quartz.

Under the microscope numerous varieties of spherulites are to be distinguished. In some phases of the rock, small, almost perfectly spherical ones with a perfect extinction cross, are seen crowded together or ranged in the form of axiolites. (Fig. 17.) The much contorted white stripings of a mass of dark aporhyolite exposed near the Goodman Place have been produced by chains of such axiolites standing out from the dark

background of a devitrified obsidian. This chain is locally enlarged by the occurrence in it of a much larger spherulite or at other times of a lithophysal cavity. (Fig. 9.) The central line of the axiolite formed by the centers of the several spherulites is here apparent.

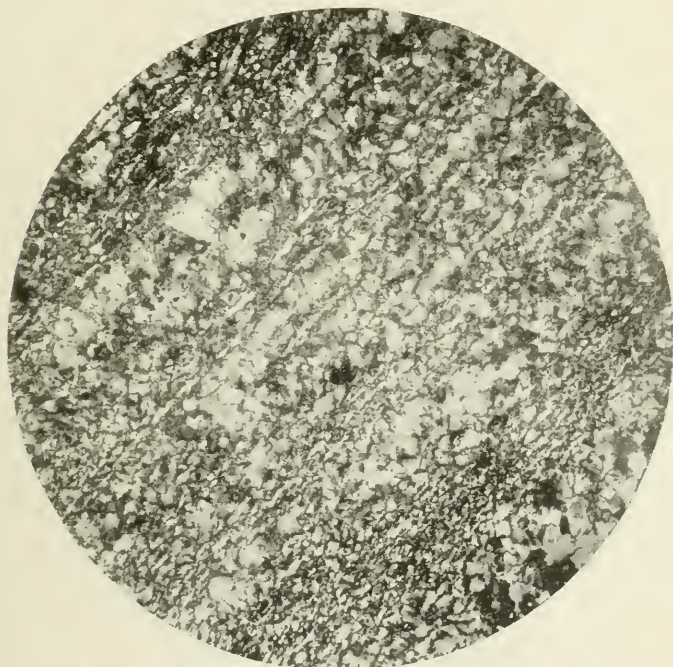


Fig. 17.—Photomicrograph of axiolites in aporhyolite from Marcellon area.

In other sections of the aporhyolite are found eccentric or fan forms. A variation of this form is that shown in Fig. 14, where a granular spherical quartz-feldspar mass is surrounded by a narrow, well-defined rim of radial feldspar of uniform width, from which rim on one side large orthoclase fibers radiate until they meet similar fronds from other centers. In ordinary light the three stages of growth of such spherulites are beautifully shown by the varying content of iron, this material being most abundant in the center, less abundant in the surrounding narrow zone, and rare in the outer radial growth.

The granular centers of such growth forms are explained by a recrystallization of the original aggregate.

In the slides there also appear roundish, well-defined, cryptocrystalline areas of feldspar, with indistinct radial arrangement. These areas have a dirty pink color in ordinary light, and are

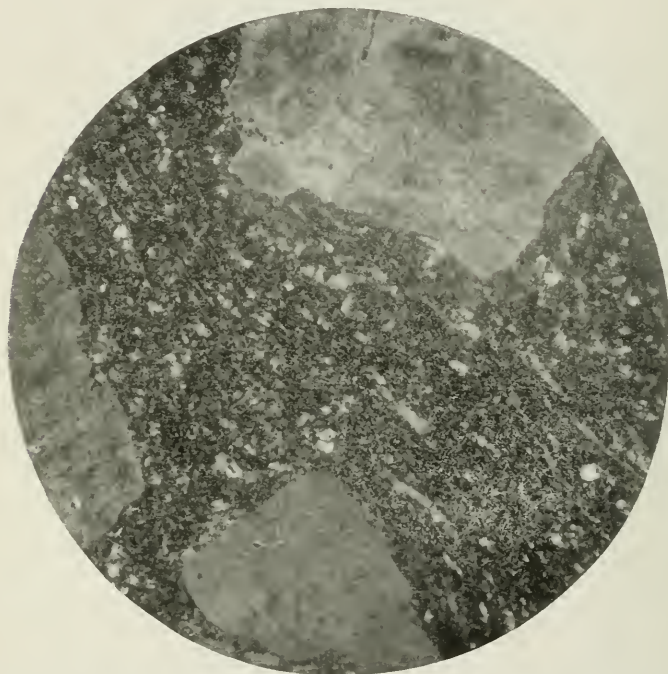


Fig. 18.—Photomicrograph of flow texture about phenocrysts in aporhyolite from Marcellon area.

almost black under crossed nicols. Where in contact with the coarsely fibrous growths, they have automorphic outlines.

The largest spherulites, like those shown in frontispiece, are seen under the microscope to be composed largely of granular quartz and feldspar, but not uncommonly, especially near the peripheries, a radial fibrous structure can be made out. The granular texture is undoubtedly due to the recrystallization of the spherulite. Perhaps the most striking of all the spherulite forms are the patchy arborescent ones seen in a few of these large spher-

ulites (Fig. 15). These make up spherulites so large that the lower powers of the microscope bring only a portion of the spherulite into the field.

The eutaxitic varieties of the aporhyolite exhibit a special phase



Fig. 19.—Photomicrograph of granophyric intergrowth about feldspar phenocryst in aporhyolite from Marcellon area.

of rhyotaxitic or fluxion texture in alternating lenses or *schlieren*, which differ in texture or in composition, or both. The prominence which this texture now has is explained largely by devitrification and by secondary coloration, but the original lenses in the rock have governed the distribution of the secondary products.

V.

LATER INTRUSIVES AND EXTRUSIVES.

In nearly all of the areas the acid rock making up the greater mass of the material is cut by dikes of a somewhat altered greenish rock. In the Marcellon area, where this type of rock has its greatest development, it has been found to have the composition

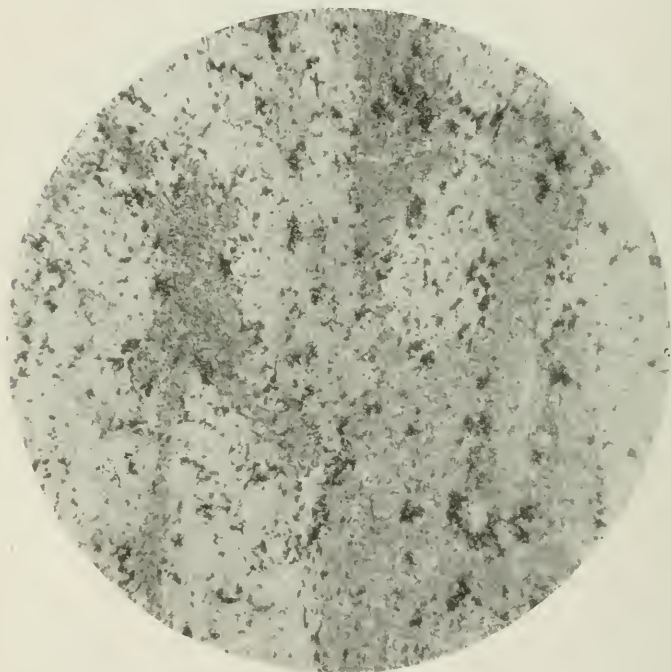


Fig. 20.—Photomicrograph of eutaxitic texture in apophyllite from Marcellon area.

of an augite andesite. The uniform characteristics of these dikes throughout the province and a determination of the silica in the rock of one of the Marquette dikes are grounds for believing that none of them varies much from this composition. The dikes of this rock cut the acid rocks at a steep angle, and throughout the province strike N. 45-90° E. At Montello they vary in trend only between N. 25° E. and N. 90° E.; at Marquette they run approximately N. 45° E., and at Observatory Hill their

course is nearly due east and west. At Marcellon a great belt of this rock, with a nearly uniform width of one hundred and fifty feet, trends N. 55° E. for the greater part of its extent, but has a considerably greater northing near its southwestern end. This material contains amygdules and is apparently not a dike at all. At Taylor's Farm the exposure of augite andesite is separated



Fig. 21.—Photomicrograph of ataxitic texture in aporhyolite from Marcellon area.

from the acid rock by a shallow covering, so that its trend was not made out.

Dikes of acid composition are found at Observatory Hill and at Marquette. At the former locality is found a granite porphyry in two ramifying dikes which trend north and northeast respectively, crossing the dikes of meta-andesite, as well as the earlier acid rocks.

VI.

CONCLUSIÓN.

The crystalline rocks of the province are found at a number of places to be unconformably overlain by Potsdam sandstone, and at Baraboo to lie beneath quartzite which has been assigned to the Upper or Middle Huronian. Their age, therefore, is certainly pre-Cambrian, and probably Archean. Cutting the main masses of crystalline rocks are intrusions of two different periods.

The analyses of the crystalline rocks show that the granites and metarhyolites of the Fox River Valley agree closely in chemical composition. The average of the soda-potash ratios for the various areas is 2.38. The later acid intrusions show high soda-potash ratios not far from this figure. It furthermore appears that the soda-potash ratio is greater in the eastern and western parts of the area than in the central part. From west to east the ratios show a diminution to the center of the area, and then an increase to the eastern extremity.

In the zone bordering the granite on the east and south, including the areas at Berlin, in the northern part of the Marquette area, and that of Observatory Hill, the textures of the rock are porphyritic with in places only faint traces of linear arrangement of the magnetite particles in the groundmass. In an outer zone, including Utley, the southeastern part of the Marquette area, Marcellon, Endeavor and Baraboo, the rocks are metarhyolites showing beautifully developed surface forms, breccias, spherulites, etc. In other words, in going outward from the granitic areas in an easterly, southerly, and southwesterly direction, one passes from granite types through rocks of intermediate texture, to typical surface volcanics.

The chemical, mineralogical and textural features of the rocks of the several areas suggest genetic relationship. The distribution of textures further suggests the truncation of a volcanic area, the granite rocks representing the material closer to the source

of the extrusion, and therefore probably more deeply buried, and the surface forms representing the rocks near the periphery of the area. However, the areas are so few and widely separated that it may not be said that for the district as a whole gradation in texture is proved. Throughout the province no direct evidence of the location of a vent has been found.

Extensive degradation of the volcanic rocks occurred previous to the deposition of the Potsdam sandstone, leaving them as monadnocks above the pre-Cambrian peneplain.

The province of the Fox River Valley in the age and in the peculiar structural differentiation of its acid rocks presents many analogies with that of South Mountain, Pennsylvania, described by Miss Bascom,¹⁰ with that of eastern Missouri, described by Haworth,¹¹ and with the Fox Islands on the coast of Maine, described by Smith.¹² Other areas of pre-Cambrian volcanic rocks are reviewed in a paper by the late Professor George H. Williams, entitled "The Distribution of Ancient Volcanic Rocks along the Eastern Border of North America."¹³

¹⁰ The Ancient Volcanic Rocks of South Mountain, Pa., by Miss Florence Bascom, Bull. U. S. Geol. Survey, No. 162, 1896, pp. 1-124. With plates.

¹¹ The Crystalline Rocks of Missouri, by Erasmus Haworth, Reports Missouri Geol. Survey, Vol. VIII, 1895, pp. 1-222. With plates.

¹² The geology of the Fox Islands, Maine, by George Otis Smith. Inaug. Diss. Johns Hopkins University, 1896.

¹³ Journal of Geology, Vol. II, 1894, pp. 1-31.

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THE ORGANIZATION OF CERTAIN COENOBIC PLANTS

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THE ORGANIZATION OF CERTAIN COENOBIC PLANTS

The importance of the cell theory in its relation to the interpretation of the facts of morphogenesis and heredity is still quite variously estimated. Hertwig, De Vries and others accept it as a fundamental fact, perhaps the most fundamental biological fact. Hertwig insists that the validity of all hypotheses as to heredity and development must be estimated from the standpoint of their agreement or disagreement with the cell theory. Driesch, Schneider, Reinke, and the vitalists of course, are relatively indifferent to the doctrine, since in all cases, according to their conceptions, formative principles, entelechies, etc., inhere in the individual as such whether it be uni- or multicellular.

A still further group assume directly that the organization of the living substance is supercellular or noncellular. In the morphogenetic processes which develop root, stem, leaf and other organs, for example, cell boundaries are held to be of minor and secondary significance.

Hofmeister's doctrine of the growth and morphogenetic differentiation of parts and organs as due to the flow of the protoplasm in this or that direction, is a good example of an attempt to explain the manifold structures of the metaphyte as a result of the presence of a supercellular or noncellular organization of the plant as a whole. If the protoplasmic stream maintains equal transverse diameters a cylindrical stem or root results. If the stream is flattened out, a leaf results. Direct comparison is made of the growth of a root to that of a filament of *Vaucheria* and of a leaf, to that of *Valonia*. Hofmeister maintains directly that "the growth of the individual cells of a growing point is controlled and conditioned by the growth of the entire vegeta-

tive point whether it be striving toward increased size alone or toward the development of a particular shape." The formation of new cells in a growing point is then a function of the general growth, not its cause.

Hofmeister conceives that the planes of cell division in a growing point are determined under the direction of this same law. The cell plate is formed at right angles to the direction of the most intensive preceding growth. The form of an organ and its growth are determined by flowage of protoplasm in definite directions and this same flowage determines the position of the cell plate. No such flow of protoplasm is of course visible in a root tip or other growing region.

Sachs' theory of the mechanomorphoses is a much more elaborate attempt at the establishment of a supercellular or non-cellular organization in both protophytes and metaphytes. Sachs' claims on direct empirical grounds to have discovered the necessity of assuming the existence of the principle of the rectangular intersection of cell walls as a form-determining factor in all growing points. For example, the protoplasm of the root tip takes the form of a cone and cutting itself up into cells, the anticlinal and periclinal cell walls form in section two systems of confocal parabolas intersecting at right angles. The principle of rectangular intersection is a fundamental growth principle in all growing regions—a mechanomorphosis.

Sachs proposes a series of further mechanomorphoses determining various fundamental life processes in entire independence of the cell units as such. Conceptions such as these of Sachs and Hofmeister pass easily into those of a pronounced vitalism and, as noted, adherents of vitalistic theories are to be classed generally with those who fail to distinguish sharply between the organization of the cell and that of the many-celled organism.

A further group adhering to the mosaic theory of cell organization in its more modern forms affirm directly the essential identity or at least similarity of the organization of the cell and the many-celled organism, basing their conceptions largely on the discoveries of pre-embryonic arrangements of the materials of the animal egg by which various tissue- and organ-building stuffs are segregated.

To many, of course, a discussion of the morphogenetic processes involved in the development of the germ cell into the adult organism means nothing but a review of the old antithesis of preformation or epigenesis. We shall do well, however, in my opinion, to adopt here with a slight change in application, a nomenclatorial principle recently very well stated in connection with the problem of species naming, and avoid the resurrection of ancient appellatives for present day concepts unless the identification of the appellative in its old and its proposed use is determined beyond reasonable question.

It seems possible at present in the light of the known facts of cell structure to discuss the problems of the development of the germ cells into the adult, avoiding both of the old alternatives. It is plain that those who assert the similarity of organization of the cell and the multicellular body are taking no mere generalized view of the question as did the old preformationists. The resemblances between the cell and the metaphyte as a whole are certainly not on the surface. Any *anlage* in the germ cell is at least not more than "metidentical" with the characteristic of the adult which it represents.

In view of the tendency to discuss the mosaic theory purely from the standpoint of observations on highly specialized animal eggs with large and differentiated yolk masses, it is perhaps worth while for the sake of bringing the question clearly into view to make a brief comparison of the organization of the cell as known today with the organization of some very simple metaphytic plant.

We may take Rabl's figure as representing in general the more essential of the known facts of cell organization. The cell according to this view, is typically a rounded or oval but polarized structure with special parts or organs, the nucleus, centrosome, chromatin, cytoplasm, etc. In reproduction it shows a differentiation of more permanent parts, the chromosomes, which are passed on from one cell generation to another with little visible change, and a more transient active mechanism, the spindle figure which for the most part at least appears and disappears with the need for its particular functions.

The mass of accumulated and well-established facts of this sort is large and we may say the general organization of the

cell is being gradually well-determined and understood. It is well to note that these general facts of organization characterize the germ cells at least of all organisms from the simplest to the most complex. The cell of the mildew, for example, duplicates all the essential features of Rabl's figure. The germ cell of the water net, a simple coenobic alga, shows the same general structure, with nucleus and cytoplasm, chromosomes and centrosomes, having the same general relations and functions as the cell of the most specialized animal types.

We may take now, for comparison, the organization of the adult form of this same water net, an extremely simple coenobic metaphyte in which the fundamentals of organization should be readily observable. It is an oblong, hollow sack made up of polygonal meshes each of whose sides is a single cell.

It is plain that a resemblance to or representation of the organization of the water net as a whole in the cell of the water net, is to be found, if at all, in some deeper and ultra-microscopic structural elements, and it is here in pangens or determinants that such a correspondence is assumed to exist. Such an assumption regarding ultimate units of living substance is, of course, hypothetical and is made as an explanation of the fact that the germ cell develops into an entire net.

There is much to be said in favor of the simpler types of many-celled organisms as material for the study of these problems of organization. We should especially hope to get light on the nature of the organization of the metazoan and metaphytic types by a study of those forms which represent the transition from the unicellular to the multicellular organism. It is natural to expect that in these earliest, simplest cell aggregates the principles of their combination and interrelationship will be most easily discoverable.

We are confronted with all stages of cell aggregates from those which are merely temporary to and through those which are permanent, and without any division of labor and specialization in structure of the cells up to forms in which specialization of tissues and organs is just beginning to appear. Types in these latter two stages of development, may be loosely characterized as coenobic plants. They are found in widely separated groups of algae and fungi and it appears that this

transitional stage in development affords sufficient advantages and adaptations to enable its representatives to perpetuate themselves indefinitely.

Certain of these simplest cell aggregates are especially well fitted to afford us definite conceptions on the point as to whether the metaphytic organism is to be regarded primarily as a colony of individual cells. In the plant kingdom we have an extraordinarily abundant and varied series of these forms which are intermediate between the unicellular and differentiated multicellular types. It is of course not to be expected that these simple coenobes will illustrate all the principles of organization manifested in the growth of an oak from its egg. On the other hand, we may fairly expect to find in them the same morphogenetic processes as in higher types.

The water net just referred to (*Hydrodictyon utriculatum*) is one of the most familiar of these types, which by reason of its large size, strikingly definite structure, and universal occurrence in Europe and North America has been a favorite object of study both from the physiological and structural standpoint. Its life history and cell structure down to the cytological details of cell and nuclear division and starch formation are known to us through the researches of a long series of workers, among whom may be mentioned. Treviranus. Vaucher, von Mohl. Al. Braun, Pringsheim. Klebs and Timberlake, and we have here a mass of confirmed and accepted facts which may be utilized in a discussion of the morphogenetic problems involved in the development of the adult net from the swarm-spore. Naturally enough attention has recently centered on the structure of the cells and the method of their reproduction, and relatively little attention has been given to the details of the organization of the net as a whole and the method of its formation. I have continued its study in this line with a view to determining the more exact relations of the cells to each other and to the whole net and the method by which the net as a whole is produced from the swarmspores.

In the adult condition, the net is an oblong or cylindrical hollow sack, rounded at the ends, and some six to eight or more times as long as it is broad. The meshes are ordinarily described as polygons with from three to six sides. Cohn's figure

is commonly reproduced and shows the sides of the meshes, varying from three to six or more and the cells of very unequal length. The figure is, of course, schematic.

The nets as found about Madison in the lakes and in tanks in the greenhouse are very variable in size. In many cases they attain only a length of a few centimeters before producing swarmspores. In other more favored localities nets a meter in length and six to eight centimeters in breadth are found. These giant nets are usually found in openings amongst the rushes in rather still waters. They regularly show a large gas bubble in one end which is thus floated up to the surface, while the other end drags on the bottom. The tendency to imprison the oxygen liberated in light assimilation is shown by all the nets and the younger ones are regularly floated on the surface of the water by the large bubbles which accumulate in their interior.

The normal life cycle may be summarized as follows: after a period of vegetative growth each cell of the net may produce from 7,000 to 20,000 swarmspores which immediately form a new net in the interior of the mother cell. After a period of such asexual reproduction the cells may produce smaller and more numerous motile gametes which conjugate to form zygospores.

Pringsheim worked out the development of the zygospores and describes the stages as follows: after a resting period they germinate by growth and after considerable enlargement form a few very large swarmspores. These in turn produce in their further development the curious spinous polyeders and in these in turn by the ordinary methods of asexual reproduction small and very irregular nets of only 200—300 cells are formed. These in the course of a few asexual cycles return to the full-sized regular nets.

An extensive statistical study of the possible numbers of sides of the meshes and the relative numbers of meshes with each given number of sides was made by a student, Miss R. Allen, working in the Wisconsin laboratory, and are embodied in a thesis presented for the B. S. degree in 1905. The results of this study are given below in tabular form. Countings of from 200 to 3,000 meshes in a dozen nets were made and the

results calculated in the form of per cents of the different polygons found.

TABLE 1.
ORGANIZATION OF *Hydrodictyon*.
From Miss R. Allen's Thesis, '05.

Number of cells in a mesh.	Per cent in different nets runs		Total av. in per cent.
	from.	to.	
3	1	2	1+
4	7	13	8+
5	26	37	29-
6	36	50	43-
7	7	17	12-
8	1	6	4+
8+	1	5	2-

Occasional cases of two-sided meshes formed by curved cells are found. but these are plainly abnormal and result from some disturbance of the ordinary processes of mesh formation. The bulk of the meshes have from three to eight sides and in the case of the few meshes found with more than eight sides, and in the case of many of those which are octagonal, it is always possible that the opening has been produced by the destruction of certain cells after the net had been formed.

It is found at once from such a study that the pentagonal and hexagonal meshes are decidedly the predominant types. Forty-three per cent. are hexagons and twenty-nine per cent. are pentagons.

There are, however, a sufficient number of tetragons, eight per cent., heptagons, twelve per cent., and octagons, four per cent., to show that all these forms are also regular and presumptively necessary constituents of the net.

The countings from each net were averaged separately and the results are given in columns two and three. We find here that the individual nets vary considerably as to the per cent. of any particular form of mesh found in them. The number of tetragons varied from seven to thirteen per cent. in different nets: the number of octagons from one per cent. to six per cent; the number of heptagons from seven per cent. to seventeen

per cent. Still greater variation is found in the percentages of the two principal types of meshes, the hexagons varying from thirty-six per cent. to fifty per cent., and the pentagons from twenty-six to thirty-seven per cent. in different nets.

A strong tendency to the formation of hexagons is shown by these figures, as high as one half the meshes having this form in certain cases. The ideal net from the standpoint of economy of materials, combined with greatest possible strength and elasticity, would be of course composed entirely of regular hexagons like the section of a honeycomb, and if there were any meehanomorphosis capable of mathematical expression which controls the organization of *Hydrodictyon* we might expect that such a result would at least occasionally be achieved.

On the other hand, there are evidently conditions at work which have favored the formation of pentagons and hexagons and have thus partially achieved a purposeful result. The variations in the form of the polygons do not conform entirely to the laws of chance.

For a more careful study of the organization of the adult and partly grown nets, I have made a series of photographs with Zeiss micro-planars, 50 mm. and 20 mm. and the 8 and 16 mm. apochromatic objectives with length of bellows giving a magnification of from 20-60 diameters. In a few cases the nets were split and the halves flattened between a cover glass and slide, but in most cases the entire net was mounted in a hollowed slide so that it floated freely in the water without compression. The lens was focused on the nearer surface and in some cases the meshes on the farther side appear as more or less hazy outlines. Care was taken not to distort or tear the nets in mounting them, though one finds in working with them that they are quite rigid and elastic structures, and that the cells break rather than glide upon each other at the ends, so as to permanently distort the meshes.

In such photographs the size and shape of the meshes, relative length of the cells, the angles at which they meet, etc., can be determined and measured much more readily and exactly than from the nets themselves under the microscope. To get the required magnification for convenient study of the meshes

only a small part of any one net could be included on a single photographic plate. As a rule, only one photograph was made from each net. The nets were taken from the tanks in which they were growing without any microscopic examination, and the part of the net to be photographed was selected merely on the basis of its general freedom from breaks or tears, and the bubbles of gas which are frequently present in the interior of the net. The percentage of meshes of the various forms shown in a number of the photographs so obtained are given in the following table:

TABLE 2.
PERCENTAGE OF DIFFERENT MESHES IN PORTIONS OF NETS
PHOTOGRAPHED.

No. of sides.	3.	4.	5.	6.	7.	8.	9.	10.	Mes- hes counted.
	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	
Net 1.....		7+	30+	50+	7+	3+			81
Net 2.....		4+	36+	47+	8+	2+			68
Net 3.....		3+	34+	44+	14+	3+			164
Net 4.....	1+	5+	30+	50+	12+	1+			230
Net 5.....		13+	34+	33+	10+	3+			250
Net 6.....	1+	1+	40+	40+	15+	1+		1+	149
Net 7.....		7+	34+	45+	11+	3+			222
Net 8.....	1+	5+	31+	40+	18+	1+	1+	1+	223
Net 9.....	1+	7+	33+	47+	8+	2+			69
Net 10.....		4+	26+	60+	3+				23
Net 11.....	2+	16+	42+	26+	9+	3+			307
Net 12.....	3+	14+	31+	32+	14+	2+	1+		293
Net 13.....	6+	26+	31+	20+	11+	1+	1+	1+	112
Net 14.....	1+	9+	31+	40+	12+	3+			136
Net 15.....	1+	6+	30+	38+	18+	4+	2+		266
Net 16.....	7+	13+	33+	29+	9+	2+			167
Net 17.....	1+	4+	30+	45+	14+	3+	1+		331
Net 18.....	1+	11+	26+	35+	16+	6+	2+		338
Net 19.....		4+	24+	45+	22+	3+			188
Net 20.....	1+	4+	27+	42+	21+	4+			177
Net 21.....	1+	2+	22+	50+	18+	5+	1+		218
Net 22.....	1+	5+	26+	46+	15+	4+	2+		215
Net 23.....	1+	10+	28+	40+	15+	4+	1+		258
Net 24.....		5+	38+	37+	14+	4+	1+		237
Net 25.....	1+	10+	36+	37+	11+	4+			109
Net 26.....	1+	3+	28+	32+	21+	4+	5+	4+	157
Net 27.....	2+	10+	31+	36+	16+	1+	3+		130
Net 28.....		1+	18+	46+	21+	7+	5+	1+	94

From certain of the microphotographic negatives so obtained enlargements were made on bromide paper in which the details of structure may be still more readily and exactly studied and the structural elements measured. If we examine any one of these photographs as to the distribution of the different forms of meshes, we find an apparently indiscriminate mingling of

the polygons of all numbers of sides from four to eight or nine. Around any given hexagonal mesh, five, six and seven sided meshes may be found. For example, in net 3 (Fig. 1), bounding the seven sided mesh No. 7, we have four hexagons and three pentagons. Bounding the hexagonal mesh 8 we have five hexagons and one pentagon, but around the hexagonal mesh 9 we have two hexagons, two pentagons, a heptagon, and an octagon. Around the tetragon No. 10 we have two hexagons and two pentagons. This shows that the different meshes are not grouped in any characteristic fashion. There is no part of the net to be found which comes perceptibly nearer to the ideal one of regular hexagons than any other part. There is no evidence that in any region the environmental conditions have happened to be so uniform that perfect regularity results, nor that any fundamental morphogenetic principle is concerned which in some regions has come to full expression in a uniform result.

In net 2, (Fig. 2), the included angles a, b, c, d, e , in the pentagon No. 1 measure respectively $a108^\circ, b110^\circ, c110^\circ, d104^\circ, e108^\circ$, a variation of 4° in the extreme from 108° , the included angle of a regular pentagon. The included angles a, b, c, d, e, f , of the hexagon No. 2 measure respectively $a119^\circ, b118^\circ, c119^\circ, d118^\circ, e123^\circ$ and $f123^\circ$, a variation of 3° in the extreme from 120° , the included angle of a regular hexagon. In the heptagon No. 3 the included angles measure as follows: $a130^\circ, b134^\circ, c106\frac{1}{2}^\circ, d162\frac{1}{2}^\circ, e103\frac{1}{2}^\circ, f148^\circ, g115\frac{1}{2}^\circ$. The extreme variation here from $128\frac{4}{7}^\circ$, the included angle of a regular heptagon, is about 34° . It follows necessarily from the irregular mixing of the various meshes that they must be practically all irregular polygons. This is conspicuous to the eye at a glance, and the inequality of the included angles is most striking. Apparently all the figures share this quality alike. The irregularity of hexagons, pentagons, and tetragons is about equally conspicuous. There is, however, occasionally an approximately regular figure, and it might seem that such cases are a little more common among pentagons and hexagons than among tetragons or heptagons, but more careful observation shows that this is merely due to the greater abundance

of the former types, and there can be no doubt that approximately regular tetragons and heptagons are about as common in proportion to their total numbers as are approximately regular pentagons and hexagons. In net No. 3, for example, an approximately regular tetragon and three approximately regular heptagons are shown out of a total of five tetragons and twenty-four heptagons shown in the field.

I have undertaken no more exact computations on this point since in every case the approach to regularity is only approximate and comparisons, in which the terms must be defined by an arbitrarily assumed limit of variability while in reality the series of forms varies continuously from approximate regularity to extremes of irregularity, can have little significance.

It is to be noted that the irregularity of the polygons is not only in their included angles but in the length of their sides, though this latter fact is perhaps not so conspicuous to the eye. Measurements indicate that the number of sides of the polygon is not definitely correlated with the length of the cells which bound it, though there may be a slight tendency to shorter cells in the polygons with seven or more sides. In the unbroken meshes at least 75 per cent. of the cells vary less than 1 per cent. from the average length, the remainder may vary as much as 10 per cent. to 20 per cent. from the average. In the case of cells with one free end the results are sometimes quite different, and in old nets where growth is nearly complete, such cells are uniformly shorter than the average. In net No. 9 the two cells with free ends are respectively 15 per cent. and 20 per cent. shorter than the average length of the adjacent cells.

The high per cent. of hexagons and pentagons in the nets brings with it one conspicuous and constant feature. In nets 1 and 2 in about 85 per cent. of the cases three cells meet at each angle of the meshes against 12 per cent. to 13 per cent. of points in which four cells meet, and only 2 per cent. or 3 per cent. of points in which two cells meet. The points where four cells meet are of course prevailingly correlated with the three- and four-sided meshes, and the points where two cells meet with the larger seven- and eight-sided meshes.

If we attempt to determine the relative strain borne by each cell in such a system, we are confronted with a most complex

but interesting series of conditions. In a net of uniform and regular meshes floating in a medium of the same specific gravity as itself, the principal stresses would arise from waves and currents, and would on the whole be approximately equally distributed so that each cell would be required to stand the same amount of strain. As a matter of fact, however, the *Hydrodictyon* net is slightly heavier than the water and is only buoyed up by imprisoned gas bubbles; the weight of the net in water will be a factor in determining the strain carried by each cell, and further the distribution of the weight will depend on the position of the net in the water, the position of the supporting gas bubbles, etc. In addition to these variable factors, however, we have the variable size and shape of the meshes and the varying lengths of the cells themselves, all of which are factors influencing the relative strain each cell will be subjected to in supporting the net and resisting the push and pull of waves and water currents. The influence of these variable factors will of course be greatest in the immediate surroundings of any particular cell, and will diminish in their importance for that cell with increased distance from it.

If in the case of any particular cell we regard the axes of the adjacent cells as the lines of thrust or pull acting upon it and determine the resultants (Fig. 3) of these stresses as applied to each end of the cell in question, we shall find of course that these resultants almost never coincide. In such a series of irregular meshes each cell is of necessity under unequal and more or less divergent strains from its opposite ends.

It is plain, however, that the cell in every case tends to take a form and occupy a position which is in turn the resultant of the total strains upon it. This result is, however, by no means always achieved; and yet the cells are strong enough under ordinary circumstances to resist the stresses brought to bear upon them, without being most advantageously placed to do so. When the cells are curved it is very commonly in the direction of the resultants of the thrusts upon their opposite ends.

It is plain that in such a system the loads and stresses to which the individual cells are subjected as units vary to a considerable degree, and in view of the known influence of tension and pressure upon growth it becomes a question of some inter-

est to know in the case of any two cells of unequal length what relative portions of the stresses of the net as a whole they each support.

In view of the data as to the influence of pressure in determining the axis of growth of the swarmspores which we find in studying the development of the net, the suggestion is strongly given that the relative length of the cells of the adult net should be correlated at least in some degree with the relative degrees of tension and pressure to which they are exposed. In a net of such variable meshes the problem is, however, too complicated to be settled by direct determination of the relative stresses to which each cell may be subjected.

The *Hydrodictyon* net, in spite of its irregularities, is, as noted above, a highly adapted and specialized structure from the standpoint of its rigidity, elasticity and the distribution it gives its cells. The high percentage of pentagons and hexagons taken together, bring it well up toward the standard of a successful construction from an engineering standpoint both for economy and distribution of material.

On the other hand it conforms in no respect to the requirements for an ideal construction for its purpose which should consist of equal and regular hexagons or for greater strength of triangles. The nets are subjected to both longitudinal and transverse bending and stretching stresses from the waves and currents and old nets are always more or less torn and deformed, showing that any increase in rigidity and elasticity would be an advantage. Whether the nets are being improved and approaching the ideal form is not easy to determine.

Still it is plain that the organization of the net as it is at present, affords great advantages over the habits of life of its protophyte ancestors. The individual cells of the net supported and anchored as they are in a fashion to allow the free circulation of water around them and floated up by the gas bubbles imprisoned in the interior are quite ideally placed for all the processes of feeding, breathing, light assimilation and removal of waste materials.

Our question now is, how is this organization of the adult net achieved in the case of each individual, and how is the capacity to produce such a net transmitted in heredity? Let

us trace the stages of reproduction in the net with a view to determining the factors in its genesis. As noted, the adult colony is a strict coenobe. The cells are all alike and are totipotent—each capable of reproducing the entire organism. Klebs has brought a great deal of evidence to show that the cells are entirely plastic as to the time when reproduction shall occur. According to Klebs it is a matter of environment wholly which determines how long the cells shall grow before they reproduce themselves. Whether sexual or asexual reproduction shall occur he also holds is a matter of environmental stimulus. I shall not recapitulate his evidence here since in any case it is clear that any predetermined cyclic succession in the alternation of vegetative growth and reproduction would be an expression of intracellular organization while we are concerned with the organization of the net as a whole. It is to be noted that while Klebs' experimental data as to the influence of environment in determining the time and kind of reproduction are of great interest, the facts of periodicity to be observed in the ordinary normal course of development of these plants must not be overlooked. Under a given set of normal conditions the plants grow to a certain average size and then reproduce. In any one of the four or five tanks in which my material was growing it was always possible, after the first two or three weeks, from the date of their appearance to find nets in all stages of development from the smallest to the largest, and only the largest are found producing swarmspores. They are all under the same conditions, except that the younger nets perhaps float a little higher in the water, forming a layer above the older ones, which from their size extend deeper down. There is thus a definite life cycle, which under normal conditions in summer the plants pass through. A net reaches a certain size and age before it reproduces itself, when it has reached that size or age, it forms spores, though it is under the same conditions as other younger nets, which continue to grow vegetatively. Vegetative growth and reproduction alternate normally and form thus a life cycle with a certain periodicity to some extent at least internally determined. When reproduction begins a further daily periodicity is shown, which again is not entirely determined by the alternation of day and night, since Klebs himself has observed

this periodicity may exist for some time when plants are kept in total darkness. It is interesting to know, as Klebs has shown, that environmental factors may be so manipulated as to force the plant to grow or to reproduce at the experimenter's will, but it is not to be forgotten that the inner organization of the plant cell itself provides the capacity for a definite cyclic form of development under practically uniform external conditions, and that it is in this fashion that the plant actually grows and reproduces itself in nature.

There is also a periodicity in the appearance and disappearance of these plants in the green house, as I have noted for several years. They appear in greatest abundance from the middle of August to the middle of October.

A less vigorous cycle of development occurs in May and June, and a slight development may occur at some time in the winter, December or January. There is considerable fluctuation from year to year, but between such periods the nets entirely disappear, except for a few abnormal-looking fragments that may be sometimes discovered in the detritus at the bottom of the tank.

The first step toward the formation of a new net is the division of the parent cell by the process of progressive cleavage into a large number of smaller cells. The number is determined by the number of nuclei in the parent cells, and has been found to vary in ordinary cases between 7,000 and 20,000. The method of cleavage was a matter of dispute among earlier investigators, but the work of Klebs and Timberlake has settled the important features of the process. A series of radial clefts or furrows are formed running through the protoplasm at all angles with each other, and subdividing it into irregular masses which are successively subdivided in the same fashion until approximately equal oval and uninucleated spores are produced.

An examination of Klebs' and Timberlake's figures shows that this process of cleavage gives no hint of the organization of the net which is to be formed. There is no blocking out of the protoplasm into the meshes of the future net. There is also no evidence here of the operation of Sachs' fundamental mechanism of anomorphosis, the principle of rectangular intersection. The

cleavage furrows intersect at the most varying angles. There is no evidence that the organization of the future net, nor any principle of organization of multicellular organisms determines in any way the process of cleavage in the mother cell of the water net. The cleavage here is essentially the same process as is found in other spore sacks of the algae and fungi with no particular adaptations due to the special organization of the adult *Hydrodictyon*.

Cleavage is accompanied here as in other spore sacks, with some fluctuations, by a general shrinkage of the protoplasmic mass so that the oval spores are loosely scattered, no longer making a continuous layer beneath the cell wall. Vacuoles in the original protoplasmic layer, as figured by Cohn, may also contribute to increase the amount of intercellular space between the spores.

The spores, as in the case of most green algae, now become ciliated and swim about actively inside the mother cell, but do not escape from it. As to the amount of motion at this stage, Klebs and Timberlake differ, Klebs asserting that the spores remain connected by fine intercellular protoplasmic strands which limit their motion, while Timberlake finds them swimming freely in the mother cell with no protoplasmic continuity between them. There is no question, as I have been able to observe repeatedly, that Timberlake is right so far as the case of nets growing under natural conditions is concerned. Nets in culture solutions, as Klebs grew them, might show variation in a point of this sort. After a period of activity, the spores come to rest and grow in length to form a new net inside the parent cell. This is of course the crucial process so far as the shape of the future meshes of the net is concerned. The shape of the meshes and the number of their sides depends on the arrangement of the spores as they come to rest and begin to grow.

The whole spore mass is too dense and the mother cell wall is too thick to be favorable for photographing in these stages of net formation. I have succeeded, however, in obtaining a series of plates, which show the position and mutual relations of the spores at each stage in net formation. The cylindrical

form of the cells of course prevents more than a limited portion of the mother cell surface from being in focus at any one time. The outline of the mother cell is almost lost excepting in case of median optical views. No details as to cell structure or the cilia of the spores are brought out, of course, but the facts as to the position of the spores, with which we are here concerned, are shown by the photographs with sufficient clearness, and in a manner which fixes beyond question the fluctuating appearances which the spores present in these stages.

As noted above, there is a marked daily periodicity in the asexual reproduction of *Hydrodictyon*. This is especially evident in cultures grown in the green house. The cleavage of the protoplasm takes place during the night and the swarmspores are apparently completely formed by day-break. Swarming begins and the young nets are formed in late summer, August and September for example, by nine o'clock. Isolated individuals may still be in the net-forming stages later in the forenoon, but the rule is quite universal that one can only obtain the active swimming stages of the swarmspores from day-break to about seven o'clock. Conditions of illumination, of course, may vary the actual time from day to day. On bright mornings the process begins earlier and apparently is completed more promptly; on cloudy mornings it is delayed and is more irregular. Photographs were taken at all stages in the formation of the nets, using the 8 mm. objective of Zeiss with the No. 2 compensating ocular. The bellows length in the majority of the cases was 100 cm. Just before swarming begins the spores are seen completely rounded up and lying in a single layer just beneath the wall of the mother cells. They are globular in form, slightly flattened on each other, however, although there are very large intercellular spaces present in some cases. These intercellular spaces may appear rounded like vacuoles, as has been shown by Cohn. In other cases the intercellular spaces are more irregular. In still other cells they are very small, or even entirely lacking, so that the spores make a single continuous layer. The amount of intercellular space present is doubtless, as I have above noted, dependent upon the condition of nutrition of the mother cell. When the layer of protoplasm is very thick and dense the number of swarmspores will be larger;

when it is thin and vacuolar the number is smaller. If the number of swarmspores is small, larger intercellular spaces will be present between them after cleavage is complete. If it is large they will be in contact with each other. As has been described in the formation of swarmspores in *Saprolegnia*, and as I have noted in *Synchytrium*, shrinkage occurs at certain stages in the cleavage process, but independently of this, I am convinced that the amount of intercellular space between the mature swarmspores of *Hydrodictyon* varies with the conditions of the nutrition of the mother cell, as just described. The appearance of a mother cell with relatively large intercellular spaces is given in Fig. 5. The intercellular spaces here appear rounded and almost vacuolar. The mother cells which produce the swarmspores are of varying sizes, as Klebs maintains, although under the conditions in which the nets grew an average length of three to four mm. was generally reached before reproduction began.

Many of the figures are taken from different cells of the same net. It was observed that not all the cells of any one net are found producing swarmspores at the same time. On the other hand, when a net has once begun to reproduce itself asexually, the process usually continues from day to day until all or most of the cells have produced young nets.

If we observe under the microscope one of the mother cells in which the spores have been formed, as shown in Fig. 5, as the day-light grows brighter, we shall find that at some point the swarmspores suddenly begin a slow motion. This motion is hard to describe. The cells are apparently writhing back and forth but scarcely changing their position with reference to each other. The motion is doubtless due to the vibrations of the newly formed cilia, which, however, are not yet sufficiently vigorous to set the cells free from each other, or to enable them to glide freely upon each other. They continue this writhing, struggling movement for a few minutes only. The whole layer then suddenly begins to contract toward the center of the mother cell. The motion of the cells becomes more vigorous as the contraction proceeds, but it hardly appears that the individual cells are actively swimming toward the center of the mother cell. The appearance is much more as if the whole layer of

swarmspores were being drawn towards the central axis of the mother cell by a contracting mass.

The swarming motion does not begin simultaneously throughout the whole length of the mother cell. It may begin at one end and progress slowly toward the other, or it may begin at several points, or at both ends. The contraction stage also is developed progressively from one end to another of the cell or begins at various points. It continues, however, until the entire mass of swarmspores forms a dense central column only about one-third the diameter of the entire mother cell.

Generally, however, before the stage of complete contraction is reached throughout the cell the next stage begins in certain regions. In Fig. 6 we see the central column in its densest stage in certain regions, while just at the end of the figure it is still forming by the contraction of the swarmspore layer. At various points, however, an irregular cloud is seen extending from the central column, in some cases entirely to the mother cell wall. This cloud is due to the active motions of the swarmspores, which are now swimming freely about among each other, and whose motions prevent any definite outlines of the cells from being shown in the photograph. Toward the end of the figure where the contraction is still going on, the motion of the cells is much less vigorous and their outlines can here be seen, though vaguely, since even here the swarmspores are in the writhing, struggling stage described above.

This next stage, which may be described as the free swimming stage of the swarmspores, follows the contraction stage within a very few minutes. The spores seem to break away from the central column and as soon as they have escaped from it they are seen to be swimming freely in the cavity of the mother cell. Watching a preparation at this stage one can frequently observe a single swarmspore break loose from the central column at a particular point. It is immediately followed by others, but there is no conspicuous evidence that the spores that successively escape come through any one particular pore in a membrane or anything of that sort. On the other hand, they seem to break loose and swim radially outward from the position which they had in the central column. A mass of them may

have such outlines, as are shown in the lower one-half of Fig. 6. These rounded masses, however, are plainly not pressing a membrane before them, but merely consist of clouds of swarm-spores, which escaped from a certain region of the central column at about the same time. The motion is in general radially outward, but at the same time the spores are seen to be gliding hither and thither in the mass in all possible directions. In a few minutes they have collected again in a layer at the surface of the mother cell and here for a time they continue their active swimming motions, gliding among each other in all directions, but apparently never swimming back into the center of the mother cell to any great distance. A stage when the spores have reached the periphery of the mother cell on one side and not on the other is shown in Fig. 7.

The thickness of the mother cell wall at this stage is well shown in the lower right-hand portion of this figure and it is plain that the gathering of the spores at the center of the mother cell has not been due to any swelling of the mother cell wall, which might crowd them inward, as it is claimed is the case in *Botrydium*. The mother cell wall is about as dense as it has been in the stages immediately preceding; it very soon swells and becomes gelatinous, but this condition is not conspicuously present up to this time.

It is shown (Figs. 6 and 7) very clearly that when the swarm-spores leave the central column a clear transparent region of some sort which is rather sharply bounded still remains in the center of the mother cell. This clear central column has the appearance of a membranous tube, which contained the swarm-spores and from which they have now escaped. The evidence that it really has something of the nature of a tube is quite conspicuous in the corresponding stages in the production of gametes. In these cases the gametes are frequently seen swimming or gliding lengthwise in this mass toward a point in the mother cell at which an opening to the exterior has been formed for their escape.

There can be no question that in this stage in which the swarm-spores leave the dense central column and arrange themselves on the periphery of the mother cell that they swim freely in all directions, showing no such intercellular connections as

Klebs describes. They are independent cell units, and the positions which they reach upon the inside of the mother cell wall are determined by a variety of factors in their environment to which they each respond as independent organisms.

Having reached the periphery, they continue to swim about with, however, constantly decreasing freedom, and very soon their motions are limited to such simple writhings and strugglings as they showed in the first stage of their activity. This condition of gentle motion continues for a relatively long period, their activities becoming gradually less and less and it is in this stage undoubtedly that Klebs has frequently observed them, and reached the conclusion that they are continuously in connection with each other by fine protoplasmic strands. Fig. 8 shows the swarmspores still in motion in this stage. As yet there is only a suggestion of the future net. The outlines of the individual cells are somewhat vague, owing to the effect of their motions, as described, but it is plainly to be seen from the photograph that in this stage they maintain a tolerably constant position with reference to each other, since the exposure required for taking the photograph was 45 seconds, and none of the cell outlines indicate that the bodies of the swarmspores moved even as much as a distance equal to their own diameter. They are in continuous motion pushing this way and that but without making permanent progress in any particular direction. It is interesting to note that the distribution of intercellular space is about the same here as in the next stage, and still the net structure is not yet conspicuous.

At this stage the central column or gelatinous mass has disappeared. It is not clear what its fate has been. Presumably it has merely dissolved or swelled up into unrecognizable outlines in the interior of the mother cell. The continued writhing motions of the swarmspores in which they glide more or less upon each other, and apparently by reason of their viscous surfaces, become more and more firmly adherent, coupled perhaps, as will be noted, with a slight growth in size of the cells, finally leads to the arrangement seen in Fig. 9. The surfaces of the swarmspores are plainly adherent here, and the motion has gradually died out. The arrangement of the cells in groups showing the outlines of the future meshes of the net is now

distinct. The impression is given from this figure that the meshes are larger and more irregular at this stage than in a mature net: but a statistical study of the groups shows that this is not the case, and that the looser appearance is due to the fact that the four-sided meshes at this stage are hardly visible, the groups which are to form them being so closely in contact that the four-sided mesh space scarcely appears. The five-sided meshes too are quite inconspicuous, while the six-, seven- and eight-sided meshes and larger more irregular openings are, of course, quite as conspicuous here as they are in the later stages of the growth of the net. The greatest care is necessary in photographing these stages to avoid pathological conditions. The cells mounted under a cover glass as they must be for photographing, soon lose their normal appearance and the following changes may be very decidedly modified by the unnatural condition in which the mother cell is placed. For this reason I have not endeavored to take successive photographs of the same mother cell in the different stages of development of the young net, but for the most part have taken only a single photograph of each cell, discarding it then for another cell selected to represent the desired stage in development. The abundance of the material available for study makes it possible to select cells for photographing in this fashion, and to be perfectly sure that the stages of development are arranged in the proper order.

Microscopic study of the young nets at the stage shown in Figs. 9 and 10 makes it perfectly clear that the mouthpieces of the swarmspores bear no definite relation to the points of contact of the different cells in the young nets, although the tendency seems to be for the mouthpiece with the cilia to face toward the intercellular space rather than to be in contact with an adjacent cell. This condition may be contrasted with that in *Oedogonium*, and other algae in which the spore regularly attaches itself to the substratum by its ciliated end. The cells in Figs. 9 and 10 are for the most part entirely globular as yet and in many of them the contrast of the dark chromatophore region with the clear ciliated mouth piece is still visible. In some cases in these figures, however, the cells have already begun to elongate very slightly so as to become elliptical rather than globular in

outline, and this has led to the flattening of the cells upon each other in the characteristic groups of three, as seen in all the subsequent stages of the development of the net. The stages represented in Fig. 8 and Fig. 9 are very closely connected and it is a question whether an intermediate stage could be found between them in which the outlines of the net meshes would be more conspicuous than they are in Fig. 8 and less conspicuous than they are in Fig. 9. It is perfectly easy in Fig. 8 to pick out particular groups of cells which are plainly destined to form meshes of each particular type found in the adult net. The characteristic groups of three are conspicuous in many cases, and in some cases the cells in such groups are seen to be already slightly flattened upon each other. Probably, however, this is merely a result of the adhesion of their viscous surfaces, since there is no evidence of any elongation of the cells in Fig. 8. In Fig. 10 the cells are seen to be either globular or very slightly elongated. We have the very beginning of net formation before us and the outlines of the meshes are for the most part entirely fixed and will plainly continue unchanged in the whole subsequent development of the plant. In Fig. 11 the cells are plainly elongated and have become markedly spindle-shaped in outline. The surfaces of contact are sharply marked at this stage owing to the development of the cellulose walls, and the cells are plainly pressing strongly upon each other. The axes of elongation of the individual cells are seen here with the utmost clearness to cut the points of contact of the groups of three. The cells are plainly elongating against the pressure of their neighbors, and in one or two cases where a cell is in contact on only one of its surfaces, its failure to elongate is conspicuous. The evidence of growth directed by functional hypertrophy appears thus in the earliest stages of the development of the net. The cells do not elongate except as they are in contact with and pressing upon adjacent cells. Their growth tendency is entirely controlled as to its direction by their contact with and pressure upon adjacent cells.

In the photographs in question the outlines of the mother cell scarcely appear, except as vague shadows. The mother cell is, however, still present at these stages, but has become decidedly thickened and is extremely transparent and gelatinous in ap-

pearance. Whether it is possible to conceive that any restraining pressure is exerted by the mother cell upon the young net at this stage is hard to determine, but later it is certain that the mother cell wall deliquesces entirely, thus setting the young net free to continue its further development independently.

At this stage when the cells first begin to elongate, the mouth-piece is scarcely recognizable and the cells appear quite homogeneously green. At a little later stage, however, when the cells are still further elongated, the interesting fact is to be noted that the green pigmented material lies in the center of the young net cell and that at its two ends where it is in contact with the adjacent cells it has become entirely hyaline.

This condition appears conspicuously in Fig. 12 where the regions of contact in the groups of three come out sharply in the photographs as transparent areas traversed by the walls of the cells, which radiate in three directions from a central point. The end of each cell has become bluntly wedge-shaped by pressure against the two adjacent cells, and this wedge-shaped region appears hyaline, as against the darker central portion of the cell. This hyaline condition is doubtless associated with great metabolic activity and growth in just these regions which correspond to Noll's regions of embryonic substance. It seems probable that the growth of the cell in this case takes place largely at its two extremities, the middle region remaining of about the same diameter as the original swarm-spores. The cell grows chiefly in length rather than in thickness in these early stages, and we have thus further evidence that the growth processes are entirely controlled by the relations of contact between the adjacent cells. There is no tendency here for the cells to expand toward the free intercellular spaces, although it would seem that the opportunities for growth were best in these directions.

It has been generally noted that the pyrenoids are either absent, or very minute in the swarmspore stages and those immediately following. In the stage shown in Fig. 12 the pyrenoids are beginning again to be conspicuous and in many of the cells they appear as clear transparent points, either imbedded in the central green region of the cell or just on the margin of this region. The cells are still spindle-shaped here,

but are becoming more cylindrical in outline. The hyaline regions at the ends of the cells are still conspicuous. The stages shown in Figs. 12, 13 and 14, are to be found abundantly during the forenoon hours. They show the gradual loss of the spindle shape and the development of the cylindrical form characteristic of the adult water net cell. The pyrenoids remain conspicuous and gradually as the nets get older two pyrenoids instead of one are shown in the cells as photographed (Fig. 14). The hyaline condition of the cell ends persists, after the cells have gained their perfectly cylindrical shape as is shown in Fig. 14, but as the cells become older and larger the green color gradually invades these hyaline areas until in the adult cell the pigmentation is homogeneous throughout.

If we analyze the processes just described it is plain that the spores in coming to rest just within the mother cell wall so as to form a hollow cylinder with closed ends have not crowded together to form as dense a layer as possible, but that they are loosely scattered, many of them in contact but with all sorts of intercellular clefts and spaces distributed rather evenly among them (Figs. 8 and 9). The sticky protoplasmic surfaces of the spores have, of course, tended to maintain any points of contact made in the last stages of swarming, as the spores gradually lost their motility. Comparing their behavior with that of other asexual swarmspores of the green algae which are set free from their mother cells this position on the mother cell wall is what would naturally be expected. Asexual swarmspores of *Cladophora* or other types while swarming are spontaneously active but are also susceptible to stimuli of various sorts. They scatter from the mother cell under the influence of light, etc., and finally come to rest and germinate. The swarmspores of *Hydrodictyon* imprisoned in the mother cells may well be regarded as under the same influences, and their coming to rest loosely scattered on the cell wall may be regarded as the natural result of their spontaneous motility plus chemical influences due to the entrance of food salts from without the mother cell and the accumulation of wastes within, which might naturally cause them to be rather repelled than attracted together and to seek a loosely scattered position on the cell wall adapted to their reception of food from without and the escape

of waste products. Their arrangement shows no tendency on their part to crowd together and a simple observation which I have had many opportunities to make, shows that at least no strong mutual attraction exists among them. Frequently, in mounting parts of nets at this stage, cells with swarming spores are cut or broken. In such cases the spores for the most part swarm out, though if the cut is at the end of a cell some swarmers may not find their way to the opening. The swarmspores which escape scatter and though many of them may never get far from the mother cell, they never in my observation tend to aggregate or form a net. The spores which remain in the mother cell may form a few irregular strands, but there is no regular mesh formation.

It is not easy to keep such preparations in normal condition, and the subsequent fate of such escaped swarmspores needs further study. I have never observed their further development, and they apparently disintegrate without showing any tendency to elongate as they would under normal conditions in the mother cell.

Returning now to the spores under normal conditions in the mother cells, we may conclude that their peripheral and loosely-scattered position, so far as the evidence goes, is due to the same activity and environmental stimuli as control the swarming and position of germination of alga swarmspores in general with the added limitation of their confinement within the mother cell wall. There is no evidence so far of the working of any organizing principle determining the structure of the future net except this one fact that the breaking down of the mother cell wall has been delayed to such an extent that the swarmspores have come to rest before their escape.

The spores now begin to grow and this first growth is a slight expansion in all directions, as is shown in Timberlake's preparations and figures, though this growth is not easy to establish by measurements in the living condition owing to individual variations (compare Figs. 8. 9. 10). This enlargement of the cells leads to their crowding together more closely and the intercellular spaces are thus reduced. Cells which have lain free or were in contact with other cells on only one side are perhaps thus crowded against cells on several sides. Cells that were in

contact with several cells at first may tend to glide upon each other so as to occupy the free space to the best advantage. As crowding develops there will be an increased tendency to the arrangement in groups of three, which is already conspicuous (Figs. 9, 10), since this arrangement brings the spore masses into the smallest space. Thus apparently each cell in the great majority of cases comes into contact with at least four other cells, though a fair per cent. may come in contact with five, some with as many as six, and a few with only two or three cells—all of which conditions are recognizable in the adult nets.

Where the crowding is greatest a second inner layer of cells is found, by whose development the inner meshes are formed and the net is made two-layered in certain regions. Sometimes, perhaps, this doubling of the net may result from other disturbances than those of overcrowding.

With the establishment of these points of contact and the resulting pressure, a change in the growth of the cells becomes at once apparent, and this, too, of a rather surprising character. One might expect under such conditions of incipient crowding to see the cells expand in the direction of the free intercellular spaces and become thus deformed in outline in the effort to occupy all the available free space. On the contrary, the intercellular spaces are seen to grow larger. The cells, instead of swelling into the free spaces, receive a stimulus at their points of contact with their fellows which leads immediately to the establishment of a favored axis of growth which, as appears in the further development of the net, is placed symmetrically with reference to the points of contact between adjacent cells. As a result of this favored axis of growth in each cell, elongation in one diameter replaces the former growth by equal expansion in all diameters. The cells become first spindle-shaped and then oblong. The spindle-shaped stage is a conspicuous one. The cells are seen to be regularly in contact at their narrowed ends and the outlines of all the different forms of meshes found in the adult net are now to be distinctly recognized. (Figs. 10, 11.) The elongation of the cells leads of course to further crowding and there may possibly be as a result some further gliding of the cells upon each other. This would still further favor the development of the groups of three which

are so constant a feature in the adult nets. Each cell will tend in crowding to develop such points of close contact at each of its two ends, and we thus get the constant structural feature of the prevailing type of meshes, the pentagons and hexagons of the adult nets.

There can be no question, I think, that the axis of elongation in each cell is determined as just described, by contact and pressure stimuli from its fellows and we have thus a most striking case of functional hypertrophy of the type described by Roux and others for so many tissues of the metazoan body. Functional hypertrophy is a principle of development of the individual cell and not of the net as a whole. The apparently spontaneous activity in swimming, during which the cells reach their position on the mother cell wall, is also, of course, due to an inherent character of the cells, which they have in common with other swarmspores.

The shape of the meshes must be conceived as due to the interaction of the individual cells, each endowed with the capacity to react most delicately, as alga spores are known to do, to all sorts of chemical, contact, and other stimuli. The net is formed by the aggregation of the spores as a colony of independent but sensitively interacting units. We have here the same biogenetic principle of cellular interaction which is recognized by Hertwig as an essential element in all morphogenetic processes in *Metaphytes* and *Metazoans*.

If we examine this process from the standpoint of other familiar theories of ontogenetic development, their inadequacy as compared with the conception of cellular interaction becomes still clearer.

If, for example, the elongation is considered merely as an inherited growth habit predetermined in each cell independently of any influence from adjacent cells we can not imagine that any such mesh formation as takes place should occur. Cells lying side by side might elongate in perfectly parallel directions or they might elongate at right angles to each other and produce T-shaped figures, zigzags and filaments as well as occasional meshes, when the axes of growth of a considerable series might happen to meet at the proper angles.

Pringsheim's doctrine that there are predetermined growing points on the spores which bud out and thus lead to their elongation, provides no better for the origin of the meshes since, unless the growing points of adjacent cells happen to be in contact, no net would result and we should have essentially the same confusion as would result from a merely chance elongation of the cells.

Pringsheim based his conception of the growing points on the structure of the polyeders. These are, however, as noted, entirely irregular spinous structures and give little ground for a comparison with the adult net cells. If the net were made up as it is conceivable that it might be, out of stellate or T-shaped cells, there would be more ground for Pringsheim's suggestion. None of those who have worked on *Hydrodictyon* since Pringsheim's time have accepted his hypothesis, though to be sure, no one has attempted a very thorough analysis of the morphogenetic factors in the development of the net. The spines of the polyeders are probably to be compared morphologically, as Pringsheim also did, with the protective outgrowths from the marginal cells of the platelike colonies of *Pediastrum*.

Elongation in any direction, whether determined by chance or by the position of special growing points, but independent of the points of contact with adjacent cells, could produce no such series of meshes as we find in the adult nets, no matter what the arrangement of the cells might be at the start.

It might be urged again by those who hold any form of the mosaic theory of germ development, that the place which each spore is to take in the future net is predetermined in the mother cell, that the position and axis of growth of each cell of the coming plant is already mapped out in the cylindrical protoplasmic layer of the cells of the preceding plant. This conception is an easy one. The mother cell has the general form of the future net and it would seem quite conceivable that in the organization of this mother cell the form and position of each element of the next generation should be outlined in all their proper space relations and that cleavage should fall on the lines so predetermined.

If mosaic development can occur anywhere, it should appear in *Hydrodictyon*. The facts are, however, as noted above, that

there is not the slightest trace in the arrangement of the cleavage furrows of any such predetermined organization. The furrows cut the protoplasm up progressively with no suggestion of any relation to the lines of the future net, and when the spores are delimited and rounded up, they proceed to swarm about until no trace of their previous arrangement in the cylindrical protoplasmic layer of the mother cell can possibly have been preserved. We can hardly imagine that the most thorough believer in the localization of the organs of the adult in their proper space relations in the egg protoplasm of an animal, would defend his views in the face of a case in which blastomeres were set free in the interior of the egg membranes, and should swarm about for half an hour before coming to rest and continuing their development.

There seems to be no escape from the conclusion that the organization of the *Hydrodictyon* net depends upon the interaction of the cells which are to compose it and that whether a spore is to become a side of a four, five, six or seven-sided figure and what angle it will make with adjacent cells, determining thus the proportion of its contribution to the general rigidity and elasticity of the whole, is determined by the relations it assumes with its fellows at the time the net is formed. The fate of the cell is strictly a function of its position plus its own independent organization with the resulting capacity for interaction with its fellows.

There are perhaps various possibilities as to the interpretation of the working of the contact stimulus upon the cells. It is probable that the points of contact will be points for the reception of special chemical stimuli due to the giving off of waste or secretion products from the protoplasm of the rapidly growing cells.

It is plain, too, that the surfaces actually in contact and flattened against each other are from the standpoint of food supply from the surrounding medium at a disadvantage as compared with the fully exposed surfaces of the cells. This relatively greater opportunity for absorption of food on the part of the exposed surfaces may be considered as a factor in their greater dimensional increase and hence according to the method of growth which we assume is a natural result of increased

feeding of a given area of cell surface, we should have increase in all directions resulting in a bulging of the cells into the intercellular spaces or a growth in some one or more directions according to whose orientation different forms would result.

The points of contact might also be considered as regions in which dynamic influences, electrical or vibrational, of any sort might be transmitted from one cell to another with the result of influencing their growth directions. As against all these possible interpretations of the contact stimuli, I am inclined to take what seems to me the more simple one of the direct contact and pressure effects which the cells exert upon each other in their growth. That they actually do press upon each other is most clearly indicated in the accurate dovetailing of the cell ends where they meet at the angles of the meshes of the adult net. This dovetailing is conspicuous from the very earliest stages in the growth of the net and still earlier before the cells begin to elongate they are commonly more or less flattened against each other. There is every indication from the very beginning of the organization of the net that its cells are under mutual pressure and support more or less weight according as the adjacent cells press them upon symmetrically placed and opposite points of their surface or more or less obliquely from one or another of their sides.

The cells are thus from the beginning called upon to do a certain amount of work to maintain their form against the pressure of their neighbors and in their elongation in the axis of pressure against their points of contact; and it is plain that this pressure and the work required to overcome it may increase.

We have thus in the pressure generated at their points of contact a constant mechanical factor, acting upon the growing cells and tending to modify their form directly. Since the elongation of the cells must increase its superficial area so long as the young net is contained in the mother cell, this factor will be an increasing one by whatever degree the mother cell wall offers resistance to its expansion. That this resistance counts for something is shown frequently by the bulging form of the free end of a net which has partly escaped from the mother cell. The growth of the net as a whole imposes upon the unit cells in their interaction upon each other, an additional

outlay of energy beyond that which would be required for the growth of each cell as a free individual, and we can hardly avoid the conclusion that this external factor of pressure, exerted from constant points on the surface of the cell, must influence its activities more or less profoundly.

The pressure of the cells on each other is of course to be distinguished from their pressure on the gelatinous semi-liquid mother cell wall, which could hardly be conceived as producing a contact stimulus. We should conclude, then, from the relative position of the cells in the net and their necessary relations of mutual pressure, that this mechanical contact stimulus is most likely to have determined the axes of growth of the individual cells, and thus the most important element in the organization of the net as a whole, namely, the elongated cylindrical form of the cells with their ends dovetailed together.

The conclusion thus reached for the water net is in entire harmony with what is known as to the influence of pressure and tension stimuli as factors in determining the relative development and form of cells in multicellular organisms. We find the principle of increased size and vigor of development with increased exertion in the line of normal functions, one of the most familiar and well-established of physiological facts. The strengthening of mechanical tissues in plants as a result of increased stress and strain and the increased muscular or other tissue development as a result of exercise are familiar illustrations of this principle. Roux who, as is well known, has analyzed the phenomena here in question most carefully, has stated the principle involved as the law of functional hypertrophy and concludes that stress of any sort acting upon a cell will tend to increase its growth or functional activity in that axis of the cell body in which resistance to the stress is offered. The water net might well serve as a paradigm for the illustration of the principle so stated. The spherical cells gradually establish an axis of elongation in direct response to the pressure exerted upon their opposite sides by the adjacent cells.

This factor is a constantly present influence as long as the cells continue to elongate. Roux' application of this doctrine in the development of the theory of an intercellular selection, going on in the development of the tissues and organs of higher

animals, of course, has no application to *Hydrodictyon*, and since we are primarily concerned with the principle as a factor in the intercellular organization of the net, as a whole. I shall not discuss the physiological foundation of the doctrine in the intracellular organization as developed by Roux and others. The fact of functional hypertrophy is so commonly manifested that it may be taken as an empirical fact without the acceptance of Roux' view of its origin in the competition of the ultimate particles of the protoplasm or any of the other conceptions as to its ultimate nature and significance for the individual cell as such.

In their further growth under the influence of the pressure exerted on them by their fellows, the cells develop into the straight elongated cylinders of the adult net, and the openings between them become larger and larger until the open, elastic framework of the full grown net is achieved with its meshes of all the various forms described above.

We see then that each mesh originates as an intercellular space or cleft between the swarmspores as they come to rest. The shape of these clefts will tend to be maintained by reason of the viscosity of the spores which will tend to maintain any grouping once attained. The gliding of the spores upon each other in their earliest growth periods may further tend to modify and develop more or less the form of the clefts and the number of cells which bound them.

By these factors of the original loose, irregular grouping, the viscosity of surface, and the displacements due to growth the degree of inequality in the interior angles, and the number of sides of the meshes, are determined. It follows that since the cells of the adult net are approximately of equal length, the variations in length not being directly correlated with the number of sides of the polygons, the amount of intercellular space, both in the earliest stages and in the adult net, will increase with the number of sides of the polygonal meshes. A net made up of hexagons gives more intercellular space, the cells being approximately equal, than one made of triangles or tetragons. From this we reach an explanation of the relative numbers of the meshes of different forms in the same net and in different nets. The greater the amount of intercellular space present be-

tween the spores when they came to rest, the higher the number of sides will be for each mesh in the adult net. When the amount of intercellular space is large, heptagons will increase in numbers. When it is small, tetragons will be more common. The operation of this principle will be interfered with when the crowding becomes so great that the spores form a double layer leading to the formation of a two-layered net in certain regions. It seems probable that this crowding of certain spores into an inside layer will always occur rather than an increase in the number of three or four-sided meshes beyond a small and somewhat definite per cent. That, however, the relative degree of crowding between the spores when they come to rest, modified to some degree by readjustments in their earliest growth stages, determines the percentage of the different mesh forms in the adult, seems clear. The correlative of this conclusion is that the amount of intercellular space between the spores in the average run of cases, favors the formation of pentagons and hexagons and thus the relatively large per cent. of these two forms of mesh is explained.

If we analyze the matter further it is plain that the amount of intercellular space between the spores, when they come to rest will depend upon the amount of shrinkage which occurs in cutting up the hollow protoplasmic cylinder of the mother cells by progressive cleavage. This shrinkage will depend upon the thickness and density of the protoplasmic layer which will vary with age, condition of nutrition, and general favorable or unfavorable conditions, under which the mother net has grown, and we thus may expect it to vary in individual cases. The varying environmental conditions under which the parent cells developed, explain the variability in the forms of the meshes in the young nets. A high per cent. of the meshes with fewer sides indicates a vigorous, well-nourished parentage, while a high per cent. of heptagons, octagons, and still larger irregular openings, is a sign of starvation, and poor development of the mother protoplasm. The normal average development of the mother cell plainly leads to that amount of shrinkage in cleavage which favors the formation of pentagons and hexagons.

In thus analyzing the factors which determine the development of the net from the free swarmspores in the mother cell,

I make no claim to completeness. That other irritable phenomena may be involved, is quite apparent. I suspect, in spite of the opposing evidence noted above, that some weak attraction may exist between the free swimming spores, which while not strong enough to lead to their crowding together in any region of the net, may still be sufficient to tend to lead adjacent cells to come to rest as far as possible in contact with each other, rather than distributed at exactly equal intervals. There is no positive evidence of such an attraction and the behavior of the cells when set free by breaking the mother cell, seems to disprove its existence, and I have hence not felt justified in assuming it as a factor in the arrangement of the spores. The observed arrangement seems also to be adequately explained on the data described. Still it may be possible that such a weak attraction is present. Chemical and dynamic stimuli as well as tactile and pressure stimuli may arise at the points of contact of the cells and may play a part in determining their interaction upon each other.

I think, however, that the facts before us with the analysis suggested are sufficient to justify the conclusion that the organization of the *Hydrodictyon* cell colony is determined by the interaction of its component cells, each being assumed to be endowed with a complex individual organization as a swarmspore and is not predetermined by nor represented in any corresponding orientation of the protoplasmic parts of the swarmspore which corresponds to it in either its space relations or compositional units identical or metidentical. Summarizing, we may note:

1. The cylindrical form of the cells and their union at their ends is developed by growth and pressure between the adjacent cells on the principle of functional hypertrophy.

2. The large intercellular spaces of the adult net have their origin in the shrinkage of the mass of the mother protoplasm during cleavage.

3. The central cavity of the net is due to the scattering of the swarmspores under the influence of chemical and food stimuli, and their coming to rest upon the mother cell wall.

4. The form of the meshes is determined by the chance grouping of the spores in coming to rest, their viscosity tending to

maintain chance contacts once established, and the slight readjustments due to gliding of their surfaces upon each other in the crowding incident to their growth as spheres and when first beginning to elongate, the number of sides of the polygonal meshes tending to become larger the greater the amount of intercellular space which is present when the spores come to rest.

Hydrodictyon is perhaps most peculiar in the fact that it develops its multicellular adult form by the aggregation of free swimming and independent spores. It is this fact which makes possible the elimination of a series of possibilities as to the relations, which the cells bear to each other, which are always present in the case of tissue cells which are produced, and continuously remain, and divide, while held in fixed relation to the adjacent cells. When cells in a free and independent condition combine in a complex structure the evidence is clear that the organization of the cell complex is the product of the interaction of its constituent units.

Cases of such morphogenetic processes still more striking than *Hydrodictyon* are found in certain groups of the simpler fungi, and we may turn to a brief consideration of them for the purpose of making more clear the possibility of the development of fairly complex plant bodies by the interaction of their component cells. *Dictyostelium*, a simple fungus growing on dung, may be taken as a type of the *Acrasieae* all of which form their fruiting bodies by the aggregation of free amoeboid cells. Brefeld first determined the main features in the life history of *Dictyostelium*, and our knowledge of this type and of the whole group as found in this country, has been enlarged and critically established by Olive.

Dictyostelium forms a stalked spore mass in its mature condition representing a considerable degree of specialization and adaptation for spore distribution. As seen when mature, the stalk is slender and tapering and the spore mass is globular and properly balanced. The whole structure appears symmetrical with properly proportioned size and height of the stalk to carry the load of spores at the top. The structure appears much more perfectly adapted to its purpose from a purely mechanical standpoint than is the water net. The stalk appears parenchymatous and is circular in cross section. It spreads at the

base into a broad disk which adheres firmly to the substratum and tapers gradually and symmetrically upward by the reduction of the number of cells in the cross section till, near the top, it may consist of a single row of disk shaped cells piled neatly one on top of the other. In slender individuals the upper one-third or even two-thirds of the stalk may be but one cell-row thick. And still it supports a globular mass of spores six to eight times its own diameter at the top. Architecturally speaking, it is probably roughly comparable in efficiency to the stems of the cereal grains in economy of materials and effectiveness. The whole body is more or less enveloped in slime from the raked amoebae by which it is built.

If we turn now to a study of the processes by which this fruiting body is formed, we find conditions directly comparable to those in *Hydrodictyon*. A spore of *Dictyostelium* falling in a favorable substratum, germinates, grows and multiplies by division, till a swarm of amoeboid cells are produced, each of which creeps about, feeds and multiplies under the stimuli of its environmental conditions, in entire independence of its fellows. Finally, however, under the influence of lack of food or some other internal change, perhaps in this case the expression of a cyclic tendency in the organization of the cell idioplasm, this period of independence ceases. Certain cells pack themselves together in a disk, adhering firmly to the substratum, and encase themselves in walls. Adjacent spores heap themselves upon the foundation so started, and as soon as each finds itself upon the apex of the disk, it ceases its amoeboid motion, packs itself firmly on the cells which have already come to rest and at once itself becomes enclosed in a wall.

The nicety with which each spore chooses its place and conforms its outlines to the requirements of the circular tapering stalk, is certainly remarkable. The stalk is formed and grows by the addition to its summit of successive cell units which, living independently up to this time, now show suddenly the capacity for such perfectly coordinated efforts. Still more striking is the change when the stalk has reached its appropriate height. Stalk building now ceases at once and the remaining mass of amoebae rounds itself up into a compact globe which is delicately poised upon the apex of the stalk. While the stalk

cells die in their position in the stalk these favored cells maintain their vitality unimpaired and each becomes a spore capable of perpetuating and reproducing the entire organism.

We have thus in this simple organism as complete a differentiation of somatic and germ cells as is found in the higher plants and animals. Specialization of the cells for reproduction, on the one hand and for support and protection on the other, takes place here just as in higher organisms.

If we attempt to analyze the morphogenetic processes involved, we find the problem appears to be a simple one. The results achieved are due to the interaction of the amoeboid cells which must certainly be regarded as highly complex organisms. But it is also clear that no assumed spatial configuration of the idioplasm of each cell to represent in miniature or in any other mechanical fashion the organization of the complete fructification, will help us in the least. To imagine some sort of mosaic in the original mother cell of the swarm which has determined the growth, division, migrations and subsequent position of each cell in the complete organism is inconceivable. There is no evidence whatever that any particular cell is predetermined for any particular position in the fruit body. The aggregation is at first of the most irregular sort and plainly influenced by all sorts of environmental conditions.

It is equally impossible to conceive that any spatial and mechanical image or representation in the idioplasm of the organism as a whole could help in determining the reactions of the cells to the situation in which they are found in each successive stage. The whole process suggests an entire absence of predetermination in the cells for any particular ultimate place or function in the organism, and their behavior is guided at each successive stage by their positions and relations to their fellows and the general environment in which they find themselves.

A simple experiment made by Van Tieghem and repeated and confirmed by Olive, shows most conclusively this lack of specific predetermination in the cells. If a mass of the amoebae which are engaged in building a single fruit body be transferred to a fresh drop of the culture medium they do not renew their vegetative growth, but scatter and proceed to build a number of smaller stalks and spore masses. As many as four

separate fructifications were thus obtained by Olive from a mass of amoebae which had originally been engaged in building a single fruit body.

If we attempt to determine the specific stimuli which control these complex interactions and reactions to environment, we are confronted with many unsolved problems. It seems fairly clear that chemical stimuli are largely responsible for the aggregation of the free amoebae. The determination of the place in which the fruit body shall develop may be, and probably is, a matter of environment. In some related genera, especially, there is a most pronounced negative hydrotropism at this stage, which may be so strong as to prevent fructification unless an opportunity is given for creeping out of the moist substratum.

The stimuli and interactions which determine the behavior of the spores in building the stalk and spore mass must be of a very complex nature to produce the delicately adjusted result which we find. It is to be noted, however, that here, as in the water net, there is no such regularity in the shape and relative position of the cells as would be found if an engineer were in control of the operations. The cells of the stalks and their arrangement remind us in no respect of a piece of brickwork or masonry unless of that old fashioned sort in which rock fragments were laid together as chance determined. No two of the cells agree in shape nor are they laid down in vertical or horizontal tiers or courses. This is most conspicuous in the parts of the stalk consisting of a single row of cells. Here the oblique walls suggest most clearly the fact that they support their load in spite of a most disadvantageous form and faulty construction. There is no evidence in the details of form, arrangement or relative position of the cells which suggests the control of any teleological formative principle, nor even that a process of organic crystallization is here going on, and yet as a whole the result is fairly symmetrical, strong, and well adapted to its purposes. When the cells in the stalks are so shaped that they tend to slide off from each other the adhesion of their walls is none the less sufficient to overcome the effects of this fault in form. If there are no tiers or courses as in a brick wall none the less the irregularities of one cell compensate those of another so that on the whole they are accurately joined together.

It is possible that contact stimuli are largely at work directing the behavior of the cells in the stalk formation. When once the foundation disk is started, its more solid surface furnishes a new set of conditions by which the still active amoebae may well be influenced. Their movement upward is plainly, in the light of Olive's observations and what is known of the movements of plasmodia in the slime moulds, due to negative hydrotropism. This influence combined with the contact stimuli which will arise when they reach the apex of the growing stalk and find themselves unable to advance farther in their retreat from the moist substratum may be major determining factors in the reactions. But it is quite possible that chemical stimuli, such as are effective in initiating aggregation may also play a rôle here. The cells which have come to rest become vacuolated and undergo profound changes ultimately leading to their disorganization. In this condition they may well be centers for the diffusion of chemical compounds which may act as specific stimuli on the cells which come into their environment. But the fact that the cells have reached a condition in which they tend to come to rest, and envelop themselves in a cell wall is, in my opinion, a prime factor. Whether this condition is reached as a result of cyclic changes in the organization of the cell itself, or has been induced by environmental conditions, is an open question, but that it is a determining factor in the behavior of the spores and has no mechanical relation to the organization of the fructification as a whole is clear from Van Tieghem's and Olive's experiments, already referred to, which show that the cells, if interrupted in building one fruit body, scatter and begin at once to build other smaller ones. If then a cell in this condition of predisposition to encyst itself reaches the highest point of the stalk and can go no farther, its building a wall about itself in this position is sufficiently clear. The tapering form and moulding of the cells upon each other may well be controlled by chemical, contact and other interactions.

The next crucial point is reached when the change from stalk building to the formation of the spore ball takes place. This seems, however, to be little more than the rounding up of the mass of cells which have accumulated at the top of the stalk at the time when the limit of safety in its further growth has

been reached. The transition is a sudden one, the stalk does not gradually widen and change into a spore mass. Increased dryness at the elevation attained may be a factor, but the instability of the support, its swaying in the lightest air currents and trembling with every slightest jarring of the substratum, may well also be factors in determining the changed activities of the cells. Watching these colonies it is apparent, as shown in the figures too, that at the stage when the stalk ceases to grow and the spore mass is formed, the body of amoebae which make the latter have been in the air supported on the stalk above the substratum for some time and the tendency to build walls and pass into the resting stage may well have been hastened by this position of greater dryness. The formation of the spore mass is probably the final expression of the tendency to come to rest which has been gaining strength by cumulative effect during the process of stalk formation. It sometimes happens that this ripening process is so hastened that the spore globe is never properly developed, but remains as an oblong mass about the upper end of the stalk.

One of the most interesting features in the development of *Dictyostelium* is the regulation of the size of the fructification according to the numbers of amoebae which are to contribute to it. It appears that when the swarm is large, a broader foundation and thicker stalk are formed and when the number of swarmers is small, the fruit body is started on a smaller scale. This is a most interesting case of an organic regulation of the type which Driesch regards as a most essential characteristic of animate as distinguished from inanimate processes. The interesting fact is that it is in this case the work, not of one organism, but of many. Driesch's entelechie, as he conceives, would be the property of each amoeba for itself and what is needed here is not a form regulating principle for each cell by itself. If there is to be a *nisus formativus* or morphogenetic principle in control of the whole swarm of amoebae, we should have to conceive it somewhat at Maeterlinck does his "spirit of the hive" in speaking of a swarm of bees and this conception is doubtless more poetic than scientific. There is no question that the size of the fructification is proportioned from the start to the size of the swarm and we get, thus, in the

interaction of these simple amoebae, an illustration of that same capacity for regulative adaptation which Driesch has shown is so conspicuous and essential a feature in the genesis of properly proportioned tissues and organs in the embryo as well as in the processes of regeneration. In *Dictyostelium* doubtless the size of the foundation is proportioned to the number of amoebae which are immediately present to contribute to its formation. The crowding at the particular point in the substratum most suitable for producing the fructification is a fair index of the number of amoebae in the region of the fructification, as a whole, and we need assume no more general relation of the swarm as a whole to the size of the foundation started, than is indicated in this fact.

Dictyostelium is only one and perhaps the best known one, of a number of related forms which can be arranged in an evolutionary series in which *Polysphondylium* is distinctly more complex in that it forms branching fructifications bearing a number of spore masses, while a further series of forms grade back from *Dictyostelium* to forms in which the fruit body is a mere globe of spores on a high and dry point of the substratum. We have then, the best of evidence that the capacity for interaction is hereditary and has been improved and specialized, these improvements being transmitted from one generation to the next.

It is to be emphasized here as in the case of *Hydrodictyon* that in questioning the existence of any spatial mechanical or other direct representation of the organization of the adult in the idioplasm of the cell, I am in no way questioning that the intracellular organization may be most complex and may be capable of acquiring and transmitting by heredity modifications which make possible still more highly perfected and delicate interactions in the organization of multicellular colonies. The *Hydrodictyon* family of algae and the whole group of the *Acrasidae* as an evolutionary series give unequivocal evidence on this point, and it is most interesting that in these groups, in which the evidence of the existence and method of hereditary transmission of a definite intercellular organization is so clear, we have also such conclusive evidence that the intracellular

organization in no way represents or reproduces the intercellular organization of the colony, as a whole.

The *Mycobacteriaceae* constitute a still further group of organisms in which definite, complex and highly-adapted plant bodies are produced by the interaction of independent cells. In this group fructifications of the most diversified forms, imitating the fruits of higher mycelial fungi, are produced with no evidence of definite tissue relations between the cells. The cellular organization is here probably of the simplest type and it is inconceivable that it in any way represents the organization of the mature fruit.

Myrococcus may be taken as a type of the group and in its stalked and branched fructification producing numerous cysts each with countless spores, we have a highly developed organization produced, however, by the mere swarming together in gelatinous masses of the minute and countless vegetative cells of the organism.

It is quite clear here as in *Hydrodictyon* and *Dictyostelium* that in environmental stimuli and the interaction of the cells themselves we have the controlling morphogenetic factors which determine the organization of these plants.

If we examine the facts as to morphogenetic processes in the development of these plants with reference to their bearing upon current theories of heredity, we are led first of all to the conclusion that the transmission of the organization of the plant as a whole is effected in such a fashion that there can be no possible reason for assuming that this organization is represented in a spatial or direct mechanical configuration of the idioplasm of the cells.

In the water net we have a multicellular plant of quite definite form and structure and with special adaptations to its habit of life in which there is no need to assume the transmission of the organization of the plant as a whole by any spatially differentiated structure in determinants, pangens, or other idioplasmic elements.

The form of the net is determined by direct inheritance from the parent cell without the intervention of an idioplasm. The internal organization of the colony, the arrangement of its parts, etc., is developed through the interaction of its constituent cells

themselves acting as complex and sensitive organisms which need not be assumed to represent in any way either spatial or in composition in their own intracellular organization the intercellular organization of the net colony. The assumption of an idioplasm in the cells which contains in some fashion the image, tendency or special potency to reproduce the organization of the net as a whole is gratuitous and unnecessary. The organization of the swarmspore, including its idioplasm and the organization of the net colony may be and probably are incommensurables in every respect.

And yet, as we have seen, the cells of the water net have all the visible organization of the ordinary cell of one of the higher plants or animals. The chromosomes are present and presumably of definite number though their small size and crowded position on the spindle has made counting them rather difficult. Centrosomes are present and apparently playing the same rôle in spindle formation and in connection with the ciliary motile apparatus as in other cells. The nuclear structures must be assumed, then, to have other functions than the representation in any way by pangens, determinants or what not, of the qualities of the multicellular organism as a whole. The doctrine that the chromosomes transmit the qualities of the cell as such and may represent the accumulated hereditary plasmas of previous cell generations is, of course, in no way affected by these considerations. There is the same evidence in the structure and division processes of the nuclei of *Hydrodictyon* that the chromosomes are a special physical basis of heredity as is found in the nuclei of other plants but we are relieved here of the necessity for that further and impossible assumption that the nuclear idioplasm represents in some spatial mechanical fashion, the organization of the adult cell aggregate as a whole.

That this complex and specific hereditary substance of the cell as such is so organized as to be divided in each cell division into equipotential systems is at once apparent in the case of *Hydrodictyon*. Each uninucleated swarmspore of *Hydrodictyon* does in the end produce an entire new net. It is proved to be toti-potent beyond all question and without the need of experimental invasions leading to possible pathological growths or regenerative processes.

I have no thought of suggesting the conclusion that the morphogenetic processes in higher and more complex plants can all be resolved into cellular interactions without the aid of some specific and hereditary qualities of structure in the germ plasm which relate to the structure of the organism as a whole.

The hereditary processes in a coenobe like *Hydrodictyon* may well be far simpler than those which have been developed in more complex and differentiated plants, but it is none the less interesting to establish that these first transitional forms in the development of metaphytes give evidence that the multicellular organism was in its earliest developmental stages no more than a composite colony, whose organization was simply the expression of the interactions of its individual cell units.

It is to be considered too, that, apart from its Lamarekian elements, the doctrine of biogenesis as developed by Hertwig and his pupils aims to account for heredity and morphogenetic processes in the most complex organisms essentially as we find them taking place in *Hydrodictyon*.

The Lamarekian element, however, in Hertwig's doctrine, that functional adaptations are directly achieved by the continued action of the stimuli involved, is distinctly not in harmony with the facts of development in the water net. The adaptations in form for strength, elasticity, reception of light, feeding, etc., are all apparently incidentally achieved advantages arising out of processes not specifically directed to the attainment of the useful end. The form and proportions of the net as a whole, are determined by the form of the mother cell and are well adapted to secure anchorage, but the form of the mother cell, as we have shown, is probably determined by functional hypertrophy due to the pressure of adjacent cells and with no reference to securing anchorage for the net as a whole. The meshed structure is well adapted to give the cells a maximum of light and food supply, but the chief factor in producing it, the elongation of the cells, reverses any tendency the cells may have to grow either toward or away from the direction from which their light and food supply reach them. To all theories involving a teleological principle as a controlling factor in life processes the data afforded by the development of *Hydrodictyon* are opposed. The adaptations noted are plainly indirectly

achieved as a result of processes which only indirectly and incidentally produce the purposeful result.

If the organization of the water net is achieved by interaction of its component cells without the presence of a corresponding organization in the idioplasm of the cells themselves, we have one case at least in which Driesch's fundamental reason for adopting the conception of a vitalistic teleological principle which shall determine and direct all life activities, has no significance. As is well known, Driesch returns over and over to the argument that material cells or chromosomes cannot be the real factors which determine the form of the organism as a whole either in ontogeny or in heredity, since to do this they must themselves be conceived as having a complicated machine structure specifically differentiated in three dimensions, and which would of necessity be destroyed in the repeated divisions which they undergo. It is inconceivable, he repeats, that an equipotential harmonic system, whose operations are based on a mechanical arrangement of its parts in three dimensions, could be divided directly into two equivalent equipotential harmonic systems. In a word, if there are form-determining elements in the egg which hold the same space relations to each other as do the parts of the adult, it is inconceivable that the egg should divide into two cells which are toti-potent—capable when shaken apart of producing the entire organism. For Driesch, preformation and epigenesis are the two horns of a veritable dilemma. If the egg be simple enough in its organization to be divided into two equipotential halves by karyokinesis it is inconceivable that it should contain the form-determining factors which control ontogeny. If it is complex enough really to contain the elements which determine the adult structure in their proper space relations, it is inconceivable that it should divide, as it does, into equivalent halves. To escape this dilemma, Driesch takes refuge in vitalism and assumes the existence of an organic self-regulating and compensating principle, the entelechie which guides the process of organic development without being itself quantitative or a spatially localized force.

If in *Hydrodictyon*, as I think is sufficiently clear, the assumption that the organization of the colony is either spatially or mechanically represented in the spore is entirely unnecessary,

we have one case at least in which we escape the vicious circle involved in Driesch's alternatives.

Driesch bases his doctrine on a study of the vastly more complex processes of regeneration and embryological development in the higher animals, but he certainly aims to give it universal application and we have a right to expect that its application should be still clearer in the relatively simple cases we are considering.

In my attempt at an analysis of the factors which determine the organization of these coenobic and partially coenobic plants we are, as I have already remarked, confronted with a mass of unsolved problems and the interpretations offered must be regarded to a considerable degree as hypothetical and to be further tested by observation of these curious plants under all sorts of natural conditions. Probably all we can say is positively known as to the irritable phenomena of the *Dictyostelium* swarmers is that they are hydrotropic and heliotropic and this last quality seems to have no special morphogenetic significance since they build their fruit bodies in the darkness just as well as in the light. In *Hydrodictyon* the facts are somewhat clearer but our conclusions as to the chemical and contact reactions are still too largely inferential.

If I have made these inferences sufficiently probable to justify their acceptance as a working hypothesis, my main object is accomplished. It is at least clear that none of those hypotheses which regard the multicellular organism as such as the seat of special regulative and form-developing principles or those which assume a sort of spatial mechanical representation of the organization of the multicellular organism in the idioplasm of its cells, can have any application to these coenobes formed by aggregation of free and independent cells.

PLATES

EXPLANATION OF FIGURES

The photographs were all made with the Zeiss microphotographic stand and the microplanar and apochromatic lenses; Figures 1 and 2 with microplanar 20 mm., Figure 4 with microplanar 50 mm., Figures 5-14 with apochromatic objective 8 mm. compens. ocular No. 2, Figure 3 with apochromatic obj. 16 mm. All figures have been reduced about one-third in reproduction.

PLATE I

Figure 1. Portion of net No. 3, Table 2, microplanar 20 mm. and further enlarged on bromide paper. Doubling of the net is shown in two places. The net is several days old, as is indicated by the number of pyrenoids in the cells, and is selected as representing the general appearance and distribution of the different meshes: 7, heptagonal mesh; 8 and 9, hexagonal meshes; 10, tetragonal mesh.

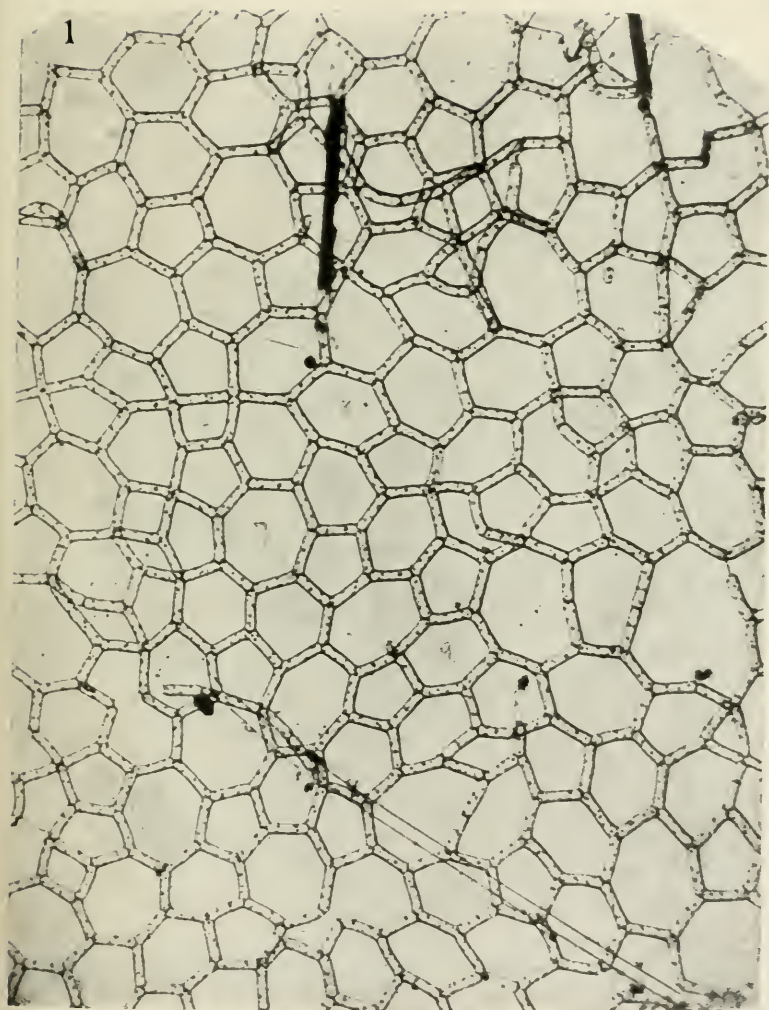


PLATE I

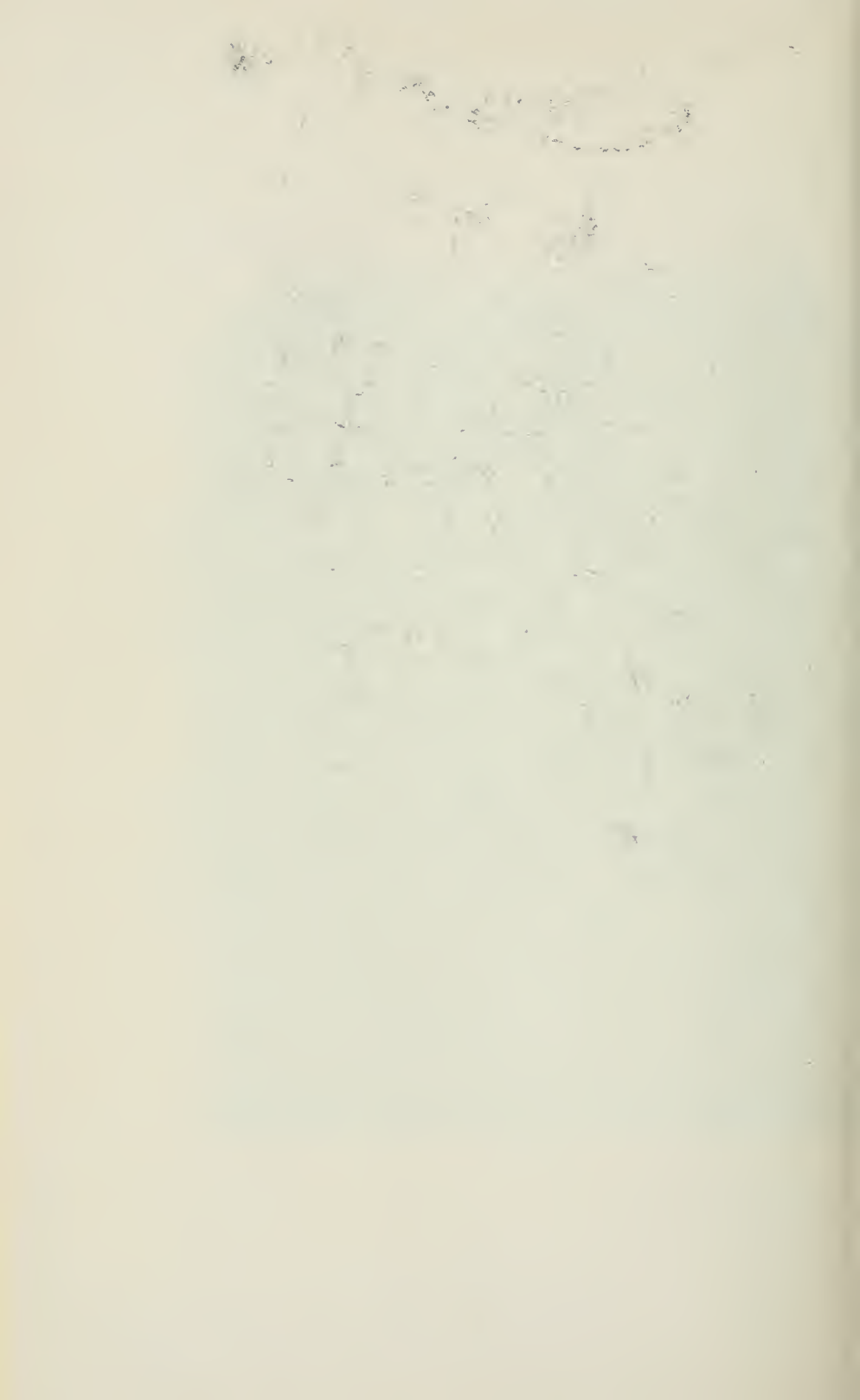


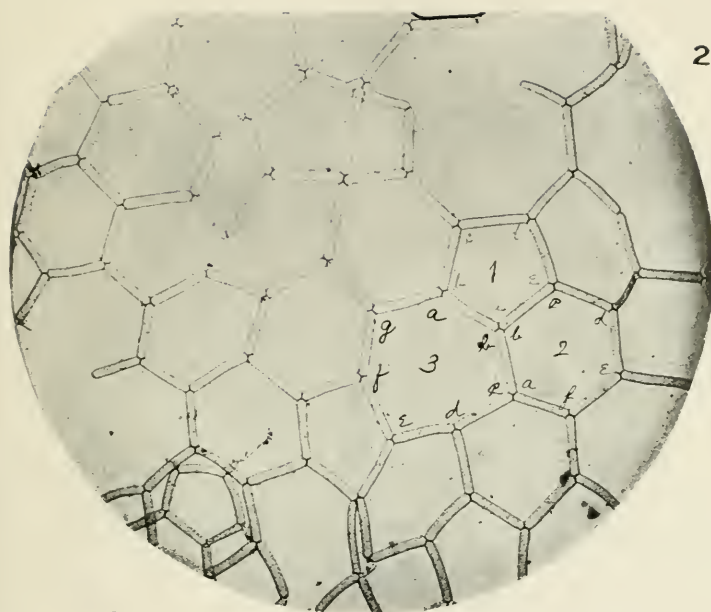
PLATE II.

PLATE II

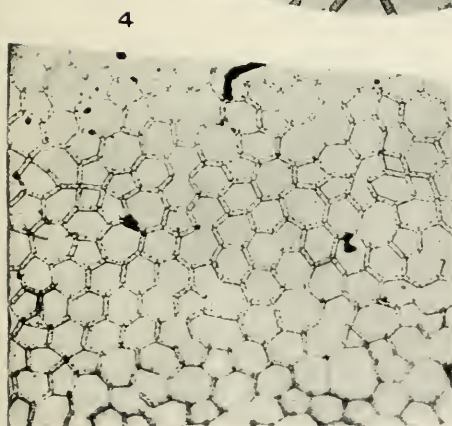
Figure 2. Portion of mature net, microplanar 20 mm. This net is old and much torn and distorted, and is in a stage just preceding reproduction. The fragment photographed shows cells with free ends and a four-sided mesh with short cells at one of whose corners a T-shaped branching of the cells is shown. The included angles of the pentagon No. 1, the hexagon No. 2, and the heptagon No. 3, are given in the text. Doubling is shown in the lower left-hand portion of the figure.

Figure 3. Lines of thrust and the resultants shown for several cells from net 2. Note that when the cells are curved the bending may be in the direction of the resultant of the thrusts from the two opposite ends of the cell.

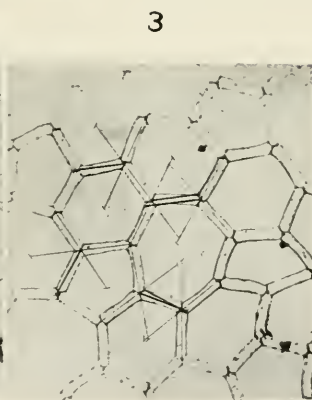
Figure 4. Portion of net 8, showing the general distribution of the meshes and degree of regularity of the different polygons.



2



4



3

PLATE II

PLATE III.

PLATE III

Figure 5. Portion of a mother cell shown at the stage when cleavage is complete and the swarmspores have not yet begun to move. They are aggregated in such a fashion as to leave spaces that suggest vacuoles in their outlines, but are merely intercellular clefts between the spores.

Figure 6. A contraction stage which follows the stage shown in Figure 5, within a few minutes. The central column of spores embedded in a gelatinous mass is shown as it is forming at the upper end of the figure. In the middle and lower portions of the figure the swarmspores have already broken away from the central column and the rounded clouds extending from the central column towards the mother cell wall are produced by the actively swimming swarmspores as they scatter in the free space of the mother cell.

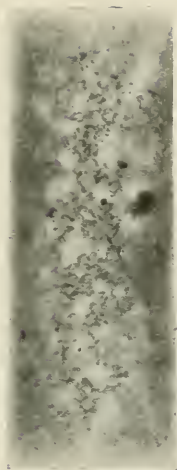
Figure 7. Showing a little later stage in which on the left-hand side the swarmspores have already reached the inner surface of the mother cell wall and are moving much less actively, as is shown by the fact that the outlines of the individual cells appear in the plate in some cases. The central gelatinous column is still seen, and the outline of the mother cell wall, which is beginning to undergo a gelatinous swelling, is also shown. On the right, and toward the bottom of the figure, the swarmspores have not yet reached the mother cell wall.

Figure 8. Showing the spores in the last stage of their swarming, when they are still moving slightly, but not sufficiently to prevent their outlines appearing with considerable sharpness on the photographic plate. The exposure for this and the preceding and following stages in net formation was 45 seconds. The spores are seen here to show in many cases the characteristic groups of three, and it is possible to determine what will be the outline of many of the future meshes of the net.

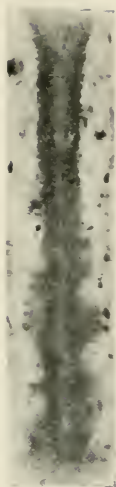
Figure 9. The spores have enlarged slightly at this stage and in some cases are already pressing against each other and taking on an elliptical outline. The outline of the meshes can be made out here in a large per cent. of the cases but four-sided and three-sided meshes are still scarcely identifiable and there are many groups of spores in which the axes of elongation of certain individuals are rather difficult of prediction.

Figure 10. A slightly later stage in which a considerable per cent. of the cells have become somewhat elliptical in outline and the meshes of the net are for the most part plainly discernible. The position of the ciliated end or mouthpiece of the spores in this and the preceding figure can be made out as a clear region contrasted with the darker green pigmented portion of the spores.

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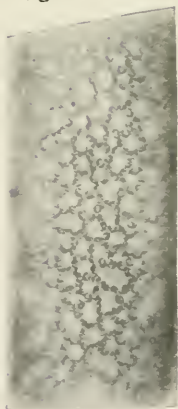


PLATE III

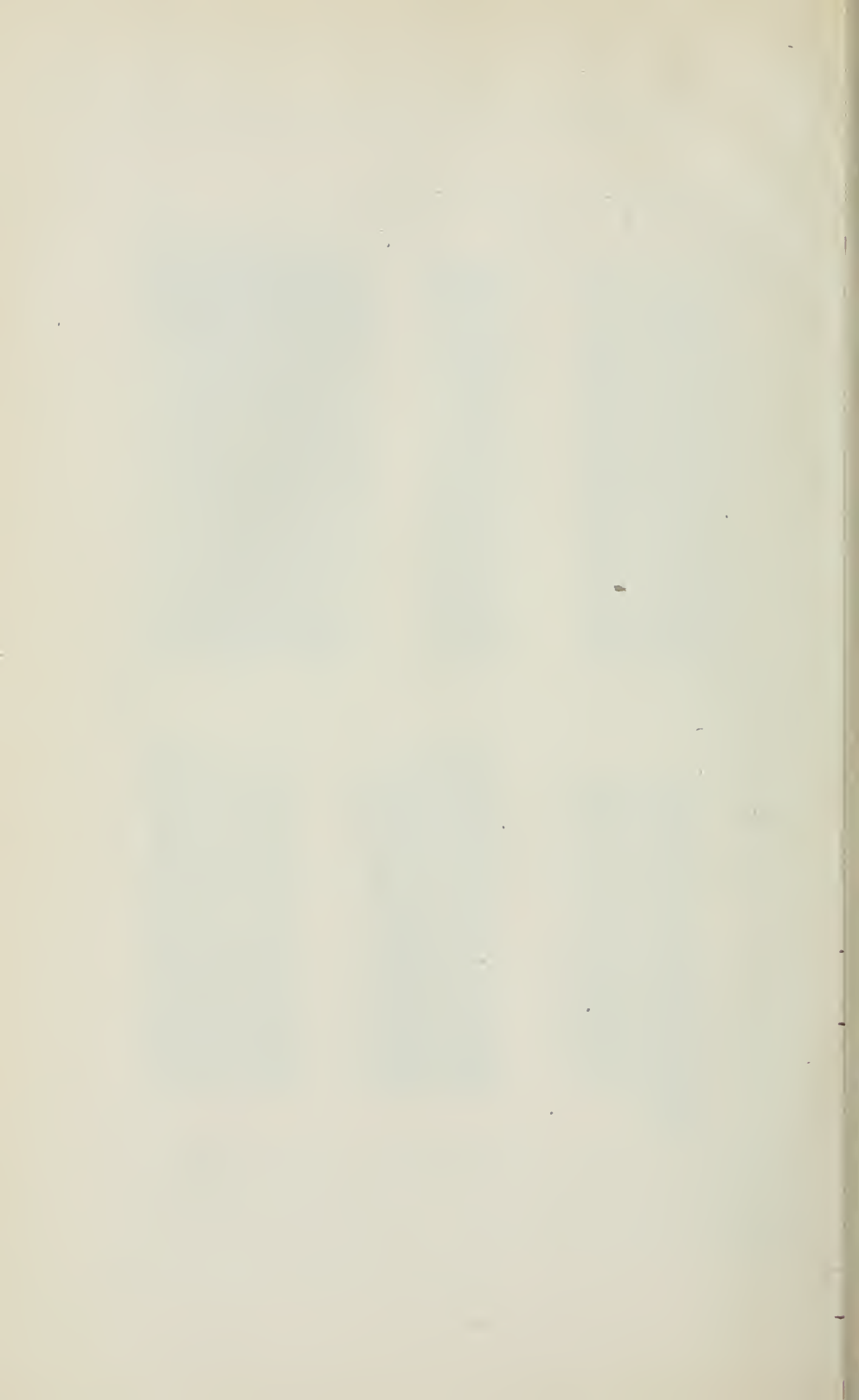


PLATE IV.

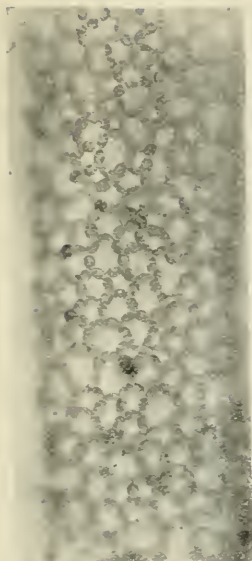
PLATE IV

Figure 11. The spores are all considerably elongated and elliptical in outline. They now appear as more solidly pigmented bodies. The outlines of the meshes are definitely marked. A cell with a free side near the middle of the figure has failed to elongate. Another cell similarly placed toward the left of the figure has grown in size but is still globular in form.

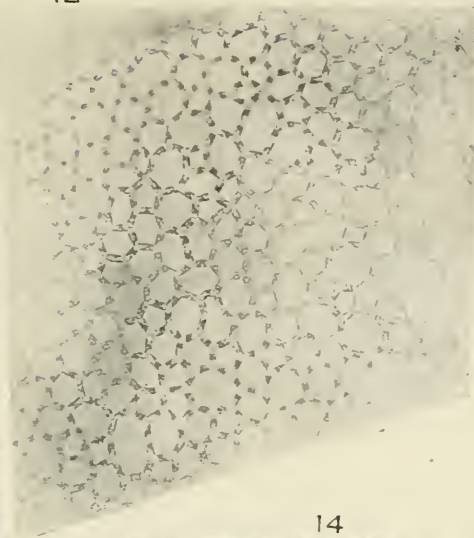
Figure 12. The cells are now taking on the characteristic cylindrical form. The pyrenoids appear as clear spots, but for the most part not more than one to a cell as yet. The growing ends of the cells appear clear and hyaline. The chlorophyl is restricted to the middle region of each cell. Such stages as this and the two following can be obtained in great abundance in the latter part of the forenoon, in August and September. The young nets are still enclosed in the gelatinous mother cell wall.

Figures 13 and 14. These represent essentially the same stage as Figure 12, and are included to illustrate still further the general types and distribution of the meshes in ordinary nets.

11



12



14

13

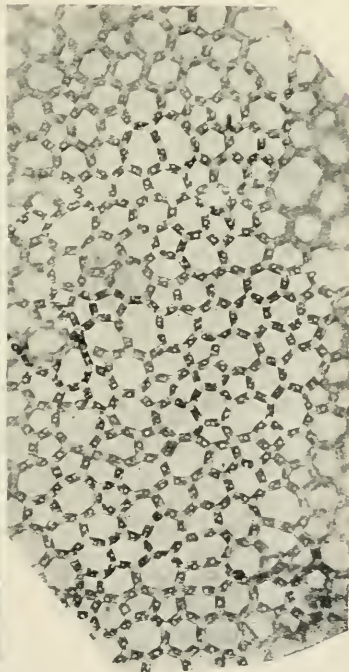
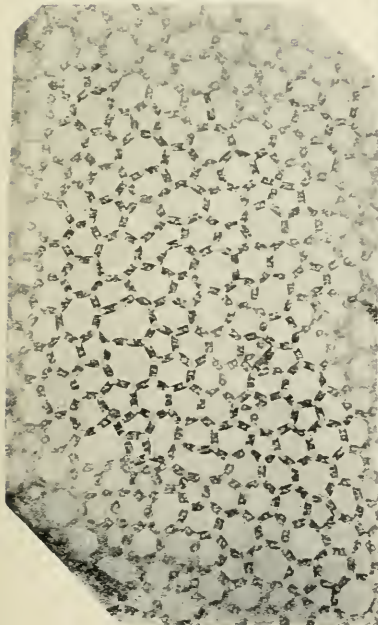


PLATE IV

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INFECTION EXPERIMENTS WITH ERYSIPHE
CICHORACEARUM DC.

BY

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A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
UNIVERSITY OF WISCONSIN

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INFECTION EXPERIMENTS WITH ERYSIPHE CICHORACEARUM DC.

Neger is to be credited with the discovery that, among the mildews, the ordinary morphological species may consist of a number of physiologically specialized forms which are limited in their occurrence to a single host plant or to a group of closely related host plants. In his work, Neger (19) used conidia of the following mildews:—*Erysiphe cichoracearum* DC., *E. polygoni* DC., *E. galeopsidis* DC., *Microsphaera astragali* (DC.) Trev., *Uncinula salicis* (DC.) Winter, *U. aceris* (DC.) Sacc., and *Phyllactinia corylea* (Pers.) Karst. He found that conidia from one host of any of these mildews would not infect plants belonging to another genus, except in two cases. Conidia of *E. cichoracearum* from *Senecio vulgaris* infected also *Lactuca muralis* in one trial out of four, and conidia of *E. polygoni* from *Ranunculus repens* infected *Galium silvaticum* in one case. He further found that, in some cases, the mildew on one host would not infect other species of the same genus as that to which the plant, from which the mildew was obtained, belonged. For example, conidia from *Artemisia vulgaris* failed to infect *A. absinthium*. Many of Neger's results rest upon a single test. It is entirely possible that had he made further trials with these plants, he would have arrived at different conclusions. In my opinion all of his results depend upon inadequate data.

Marchal (16) later announced, on the basis of a limited number of experiments, the existence of seven "*formes speciales*" of *Erysiphe graminis* DC. on various grasses. With one exception, each specialized form was found to be limited to the species of a single genus of host plant. The form on species of *Avena* also occurred on *Arrhenatherum elatius*.

Marchal gives no details of his experiments, and, consequently, it is impossible to tell how far his results are reliable. There is, in fact, considerable evidence that there are more than seven specialized forms of *Erysiphe graminis* which infect the grasses tested by Marchal. Salmon (26, 30) has found that, instead of one specialized form of mildew for all the Bromo grasses, as stated by Marchal, there are probably four or five distinct biologic forms on the species of *Bromus*. The mildew on *Hordeum vulgare* also, according to Salmon (27), while able to infect eight species, is unable to infect four other species of this genus. Salmon's other results with conidia of the grass mildew in general confirm those of Marchal.

Salmon (29) has also obtained interesting results with conidia of *Erysiphe polygoni* DC. from *Trifolium pratense*. These conidia, while able to infect *T. pratense*, will not infect other species of the same genus. Salmon has also tested *Erysiphe cichoracearum* DC., *E. galeopsidis* DC., and *Sphaerotheca humuli* (DC.) Burr. on some of their respective hosts. Many of his results rest upon a single test. The data given in most cases are insufficient for any definite conclusions.

In a series of experiments in which the specialization of conidia of *Erysiphe graminis* DC. from *Secale cereale* and *Poa pratensis* was tested, I (21) found that the mildew on both these hosts was limited to species of the same genus. Furthermore, the mildew on the blue grass passed over only with difficulty to three other species of *Poa*.

From all these results, it is evident that, in the cases investigated, with the exception of the doubtful cases recorded by Neger and Marchal, each mildew is sharply restricted to species of the same genus from which the mildew was obtained. There is also some evidence that in a few cases the specialization has gone even further, certain biologic forms being restricted to definite species of a genus.

So far as investigations have been made, the results of tests in which ascospores were used are the same as when conidia were taken from the same host. Marchal (17) and Salmon (25) have done some work with the ascospores of

Erysiphe graminis and Voglino (38) with the ascospores of *Phyllactinia corylea*, but have obtained no evidence that the ascospores can infect a wider range of host plants than the conidia.

Salmon (28, 32) has further tried the effect of injuring a host plant in various ways, and then inoculating it with a mildew which normally does not cause infection on this particular host. For example, injured leaves of barley were inoculated with conidia from wheat. The barley, under these conditions, readily became infected. The conidia thus produced on the barley, however, were unable to infect healthy barley plants, while they could infect normal wheat plants, the host from which the mildew was taken. Salmon states in his earlier paper that this does occur, but this is not borne out by his later results.

In a recent paper I (22) have shown that the mildew, *Erysiphe cichoracearum* DC., on the squash, *Cucurbita maxima*, is able, not only to infect several cultivated varieties of this species, but also to infect six varieties of *Cucurbita pepo*, two varieties of *C. moschata*, six varieties of *Cucumis sativus*, and two varieties of *Lagenaria vulgaris*. These results are in striking contrast to those hitherto obtained. This mildew, instead of being sharply limited to the species of a single genus, is capable of infecting at least five species belonging to three different genera, these genera all belonging to the one family of the Cucurbitaceae.

In continuing my investigations of physiological specialization, I have made further experiments with this mildew on the squash and tested its capacity for infecting a number of cucurbits belonging to various other species, with results showing that it is even more cosmopolitan in its habits. I have also tested the capacity of this same mildew to infect plants of other families, which are reported as hosts of *Erysiphe cichoracearum* in systematic works. The mildew occurring on species of asters was also tested on a number of hosts. This mildew belongs to the same morphological species, *E. cichoracearum*, as the squash mildew.

The methods employed were the same as I have previously

described. Seedlings of the cucurbits and sunflower were grown in four- or five-inch flower pots. In the case of the other plants tested, young plants were brought into the greenhouse from out of doors. The seed was obtained from J. M. Thorburn & Co., of New York, and Henry A. Dreer, of Philadelphia.

Simultaneous inoculations of a number of different varieties were usually made, at least one being of the same species as that from which the conidia were taken for inoculation. If this variety became infected, it was regarded as evidence that the conidia were viable. In some cases, also, some of the conidia were sown in a drop of water on a slide and placed in a moist chamber, and the extent of their germination noted twenty-four hours later. In each test, only certain plants or leaves were inoculated. The others were kept as controls.

I have put the results of these experiments in tabular form, describing the details in connection with each table.

TABLE I.—VARIETIES OF *Cucurbita maxima* DUCHESNE.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of parts inoc.		No. of con- trols.	Results.		
					No. of plants used.	Coty.		Lvs.	Date.	Inoc. pl.	Con- trols.
<i>Cucurbita maxima</i> .										
25c	1903	21	Hubbard squash	Hubbard squash	1	2	1	1906	++	—
12a	Mar. 20	...	Hubbard squash	Hubbard squash	1	...	...	April 1	++	—
33d	May 15	...	Hubbard squash	Hubbard squash	1	...	...	May 27	++	—
61b	June 18	12	Hubbard squash	Hubbard squash	1	4	1	June 28	++	—
69c	July 6	21	Hubbard squash	Hubbard squash	1	...	...	July 16	++	—
71a	July 23	13	Hubbard squash	Hubbard squash	1	...	...	Aug. 2	++	—
75a ¹	Aug. 7	14	Hubbard squash	Hubbard squash	1	...	...	Aug. 8	++	—
76j	Aug. 7	...	Hubbard squash	Hubbard squash	1	...	...	Aug. 15	++	—
77b	Aug. 7	11	Hubbard squash	Hubbard squash	1	...	...	Aug. 15	++	—
81j	Aug. 17	11	Hubbard squash	Hubbard squash	1	...	...	Aug. 15	++	—
81g	Aug. 20	11	Hubbard squash	Hubbard squash	1	...	...	Aug. 21	++	—
86d	Aug. 23	15	Hubbard squash	Hubbard squash	1	...	...	Aug. 31	++	—
88c	Aug. 24	18	Hubbard squash	Hubbard squash	1	...	...	Aug. 30	++	—
88o	Aug. 24	11	Hubbard squash	Hubbard squash	1	...	...	Sept. 3	++	—
89f	Aug. 30	13	Hubbard squash	Hubbard squash	1	...	...	Aug. 30	++	—
90c	Aug. 30	22	Hubbard squash	Hubbard squash	1	...	...	Sept. 5	++	+ ²
90i	Aug. 30	13	Hubbard squash	Hubbard squash	1	...	...	Sept. 5	++	+ ²
91b	Aug. 30	28	Hubbard squash	Hubbard squash	1	...	...	Sept. 6	++	+ ²
97i	Sept. 3	12	Hubbard squash	Hubbard squash	1	...	...	Sept. 6	++	+ ²
100	Sept. 11	6	Hubbard squash	Hubbard squash	1	...	...	Sept. 10	++	—
111b	Sept. 11	31	Hubbard squash	Hubbard squash	1	...	...	Sept. 17	++	—
111j	Nov. 5	28	Hubbard squash	Hubbard squash	1	...	...	Oct. 2	++	—
115b	Nov. 5	36	Hubbard squash	Hubbard squash	1	...	...	Nov. 11	++	+ ²
115c	Nov. 17	36	Hubbard squash	Hubbard squash	1	...	...	Nov. 11	++	+ ²
	Nov. 17	36	Hubbard squash	Hubbard squash	1	...	...	Nov. 31	++	—
	Nov. 17	36	Hubbard squash	Hubbard squash	1	...	...	Nov. 30	++	—
1907.										
118a	Feb. 12	19	Hubbard squash	Hubbard squash	2	4	3	1907	++	—
120b	Feb. 25	23	Hubbard squash	Hubbard squash	1	...	...	Feb. 25	++	+ ³
121b	Mar. 4	19	Hubbard squash	Hubbard squash	1	...	...	Mar. 4	++	—
122b	Mar. 13	28	Hubbard squash	Hubbard squash	1	...	...	Mar. 13	++	—
123c	Mar. 20	15	Hubbard squash	Hubbard squash	1	...	...	Mar. 20	++	—
124d	Mar. 23	18	Hubbard squash	Hubbard squash	1	...	...	Mar. 30	++	—
128g	Apr. 8	37	Hubbard squash	Hubbard squash	1	...	...	Mar. 30	++	—
129b	Apr. 10	35	Hubbard squash	Hubbard squash	1	...	...	Apr. 20	++	—
132b	May 7	18	Hubbard squash	Hubbard squash	1	...	...	Apr. 20	++	—
131a	May 13	22	Hubbard squash	Hubbard squash	1	4	1	May 18	++	—
					1	2	1	May 20	++	—

¹ Petri dish method.

² Small infected areas on cotyledons of controls.

³ Fair infection of one leaf and one cotyledon.

In the above table are given the results of inoculating varieties of *Cucurbita maxima* with conidia from various cucurbits, mainly from varieties of this same species. The large number of trials with the Hubbard squash is due to the fact that seedlings of this variety were used as controls in most of the experiments in which conidia from *Cucurbita maxima* were sown on other plants.

Forty-three tests were made in which conidia from varieties of *Cucurbita maxima* were sown on the Hubbard squash, twenty-two cotyledons and seventy-four leaves being inoculated. Fifteen cotyledons and sixty-three leaves became infected. Two cotyledons died before the mildew had time to appear.

In two experiments, 98h and 106d, a few infected areas were observed on the cotyledons of the inoculated plants, no conidia having been sown on them. This was probably due to some of the conidia used in inoculating the leaves falling upon the cotyledons. In several experiments, however, infected areas also appeared on the control plants. In most of these cases the infection was observed very shortly after inoculation, before the mildew had time to develop on the parts of the plants inoculated. This indicated that the plants had become infected before they were used in the experiment. In fact, for a time the seedlings were grown in the greenhouse only a short distance from an infected squash plant. Some seedlings were even found with small infected areas among those used in the tests. Conidia had doubtless been carried from the infected plant to the young seedlings in these cases.

These extraneous infections could be readily distinguished from those resulting from inoculation by their much smaller size and by their being limited to small areas of the leaf. In contrast, the patches of mycelium resulting from inoculation were large and widely distributed over the leaf, which effect was due to spreading the conidia used in inoculation over the entire lamina.

In addition to the Hubbard squash, six other varieties of *Cucurbita maxima* were tested. All of these readily became infected.

Not only could the Hubbard squash be infected by conidia from varieties of *Cucurbita maxima*, but also by conidia from *Cucurbita moschata*, *Cucumis melo*, *C. sativus*, *Citrullus vulgaris*, *Ecballium elaterium*, *Echinocystis lobata*, *Lagenaria vulgaris*, *Melothria scabra*, and *Sicyos angulatus*. With one exception, these species were first infected by conidia from the Hubbard squash. In experiments 130a and 130b, the conidia were obtained from cucumber vines growing in the Horticultural greenhouse, about a half-mile distant from the greenhouse in which my experiments were carried on. The vines in the Horticultural greenhouse were very badly infected with mildew and these tests show that this mildew is the same in its infecting capacity as that originally found on the Hubbard squash. The conidia used in experiment 135a were taken from plants previously infected by conidia obtained from the cucumber vines in the Horticultural greenhouse.

TABLE II — VARIETIES OF *Cucurbita moschata* DUCHESNE.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.	
						Coty.	Lvs.		Date.	Inoc. pl.
80a 106g 107c 108a	1906 Aug. 13 Sept. 27 Oct. 3 Oct. 6	21 24 24 25	Winter crookneck squash.....	<i>Cucurbita maritima</i> , Hubbard squash..... Marblehead squash..... Marblehead squash.....	1 1 1 1	.....	.....	1 1	1906. Aug. 23 Oct. 6 Oct. 13 Oct. 18	++ ++ ++ ++
121c 125c	1907 Mar. 23 Mar. 30	18 25	Winter crookneck squash.....	Hubbard squash..... Hubbard squash.....	1 1	.....	.....	1 1	Mar. 30 April 8	++ ++
89c 91d 106a 102a	1905 Aug. 30 Sept. 3 Sept. 17 Sept. 17	13 17 28 18	Japan crookneck pumpkin.....	Hubbard squash..... Hubbard squash..... Marblehead squash..... <i>Cucurbita foetidisistina</i>	1 1 1 1	.....	.....	1 1	Sept. 6 Sept. 10 Oct. 6 Oct. 2	++ ++ ++ ++
89g 97c 111d 111h 98k 102a	1907 Aug. 30 Sept. 6 Nov. 5 Nov. 5 Sept. 10 Sept. 17	13 13 31 31 17 18	White cushaw pumpkin.....	<i>Cucurbita maritima</i> , Hubbard squash..... Hubbard squash..... Hubbard squash..... Marblehead squash..... <i>Cucurbita foetidisistina</i>	1 2 1 1 2 1	.....	.....	1 1 1	Sept. 5 Sept. 17 Nov. 11 Nov. 11 Sept. 25 Oct. 2	++ ++ ² ++ ++ ++ ++
121a 126d	1907 Mar. 23 April 1	48 26	White cushaw pumpkin.....	Hubbard squash..... Hubbard squash.....	1 1	.....	.....	1 1	Mar. 30 Apr. 10	++ ++

¹ Only one leaf infected² Small infected areas also on cotyledons.

As seen in the table, three varieties of *Cucurbita moschata* were tested. Eighteen trials were made, thirty-six leaves being inoculated. In all the experiments except two, the conidia used were taken from *Cucurbita maxima*. In experiments 102a and 102e, the conidia were obtained from *Cucurbita foetidissima*. The mildew failed to appear on only one inoculated leaf. In experiment 97c, a few infected areas were observed on the cotyledons, doubtless due to some of the conidia used in inoculation falling upon them.

The conidia produced on some of these plants were sown on seedlings of *Cucurbita maxima* and *C. pepo*, causing full infection.

TABLE III.—VARIETIES OF *Cucurbita pepo* LINN.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of con-trols.	Results.		
						Coty.	Lvs.		Date.	Inoc. pl.	Con-trols.
11b	1906 Feb. 28	34	Summer crookneck squash.....	<i>Cucurbita pepo</i> , Golden bush squash.....	2	4	2	1	1906 Mar. 7	++	—
34b	Apr. 18	31	Summer crookneck squash.....	<i>Cucurbita moschata</i> , Winter crookneck squash.....	1	.....	3	1	Apr. 27	++	—
77e	Aug. 8	15	Summer crookneck squash.....	<i>Cucurbita maritima</i> , Hubbard squash.....	2	.....	2	1	Aug. 15	++	—
84j	Aug. 17	11	Summer crookneck squash.....	Hubbard squash.....	2	.....	3	1	Aug. 24	++	—
63b	Aug. 20	14	Summer crookneck squash.....	Hubbard squash.....	2	.....	3	1	Aug. 30	++	—
67c	July 6	23	Mammoth summer crookneck sq ¹ sh	Hubbard squash.....	4	4	3	1	July 16	++	—
76i	July 9	21	Mammoth summer crookneck sq ¹ sh	Hubbard squash.....	4	4	3	1	July 23	++	—
67b	Aug. 7	14	Mammoth summer crookneck sq ¹ sh	Hubbard squash.....	4	4	3	1	Aug. 15	++	—
68g	July 12	13	Early white bush scallop squash...	Hubbard squash.....	4	4	3	1	July 23	++	—
68j	July 17	18	Early white bush scallop squash...	Hubbard squash.....	4	4	3	1	July 27	++	—
70c	Aug. 7	11	Early white bush scallop squash...	Hubbard squash.....	4	4	3	1	July 27	++	—
71e	July 31	19	Yellow bush scallop squash.....	Hubbard squash.....	1	.....	2	1	Aug. 15	++	—
88i	Aug. 24	20	Yellow bush scallop squash.....	Hubbard squash.....	1	.....	2	1	Aug. 15	++	—
63a	Aug. 30	18	Golden custard squash.....	Hubbard squash.....	1	.....	1	1	Sept. 3	++	—
88j	Aug. 24	11	Golden custard squash.....	Hubbard squash.....	1	.....	1	1	S ¹ pt. 6	++	—
64e	July 6	18	English vegetable marrow squash...	Hubbard squash.....	2	4	3	1	July 16	++	—
67a	July 12	14	English vegetable marrow squash...	Hubbard squash.....	2	4	3	1	Sept. 3	++	—
68f	July 17	19	English vegetable marrow squash...	Hubbard squash.....	2	4	3	1	July 16	++	—
69i	July 23	25	English vegetable marrow squash...	Hubbard squash.....	1	2	1	1	July 23	++	—
70f	Aug. 7	15	English vegetable marrow squash...	Hubbard squash.....	1	1	1	1	July 27	++	—
86a	Aug. 23	15	English vegetable marrow squash...	Hubbard squash.....	1	.....	2	1	Aug. 2	++	—
88a	Aug. 24	16	English vegetable marrow squash...	Hubbard squash.....	1	.....	4	1	Aug. 15	++	—
111f	Nov. 5	33	Italian vegetable marrow squash...	Hubbard squash.....	1	4	4	1	Aug. 30	++	—
115e	Nov. 17	26	Italian vegetable marrow squash...	Hubbard squash.....	1	4	4	1	S ¹ pt. 3	++	—
119	Dec. 26	19	Italian vegetable marrow squash...	Hubbard squash.....	1	4	4	1	Nov. 14	++	—
25b	Mar. 20	24	Early sugar pumpkin.....	Hubbard squash.....	1	4	4	1	Nov. 30	++	—
69a	June 28	15	Early sugar pumpkin.....	Hubbard squash.....	1	6	6	1	Jan. 5	++	+
76a	Aug. 7	13	Early sugar pumpkin.....	Hubbard squash.....	1	.....	2	1	Apr. 9	++	—
81k	Aug. 17	11	Early sugar pumpkin.....	Hubbard squash.....	1	.....	2	1	Aug. 15	++	—

¹ One pair of cotyledons dead.² One cotyledon withered.³ One leaf not infected.⁴ A few small patches on the cotyledons of the control.

Seventeen varieties of *Cucurbita pepo* were tested. Varieties of the field pumpkin, the bush scalloped squashes, the summer crookneck squashes, the vegetable marrow, and various gourds, were used. Thirty-eight cotyledons and one hundred and twenty-five leaves were inoculated. Thirty-four cotyledons became infected, three of the remaining four having died before the mildew had time to develop. One hundred and eighteen of the inoculated leaves also became infected. One leaf died shortly after inoculation.

The conidia used in these tests were obtained mainly from *Cucurbita maxima*, but in some of the trials they were taken from *C. moschata*, *C. pepo*, and *C. foetidissima*.

No difference was noted in the capacity for infection of the various varieties tested. They were all equally susceptible to the mildew.

TABLE IV.—*Cucurbita foetidissima* KUNTH.

No. of exp.	Date.	Age of plants (day s)	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date	Inoc. pl.	Controls.
65f	1906 July 9	26	<i>Cucurbita maxima</i> , Hubbard....	1	.....	2	1	July 23	—	—
97j	Sept. 6	27	squash. Hubbard....	1	.....	3	.....	Sept. 17	+++ ¹	.....
107h	Oct. 3	27	squash. Marblehead.	1	.....	3	.....	Oct. 13	+++	.....
108e	Oct. 6	30	squash. Marblehead. squash.	1	.....	3	2	Oct. 18	++	—

¹ Two leaves infected, the third withered.

This cucurbit is generally listed in the seed catalogues under the name of *Cucumis perennis*. Seedlings were successfully infected with conidia from *Cucurbita maxima* in three out of four trials. Eleven leaves were inoculated, eight becoming infected. One of the remaining three withered before the mildew had time to develop. The conidia produced on the infected leaves were able to infect seedlings of both *Cucurbita moschata* and *C. pepo*.

TABLE V.—VARIETIES OF *Citrullus vulgaris* SCHRAD.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
						Coty.	Lvs.		Date.	Inoc. pl.	Controls.
<i>Cucurbita maritima</i> .											
53b	1906 June 18	24	Peerless watermelon	Hubbard squash	1	2	2	1	1906 ¹ June 28	1	—
68c	July 6	30	Peerless watermelon	Hubbard squash	1	2	2	1	July 16	1	—
68a	July 9	33	Peerless watermelon	Hubbard squash	1	2	2	1	July 23	1	—
68h	July 17	29	Peerless watermelon	Hubbard squash	1	2	2	1	July 27	1	—
77g	Aug. 8	40	Peerless watermelon	Hubbard squash	1	2	2	1	Aug. 15	1	—
55a	June 23	28	Peerless watermelon	<i>Melothria scabra</i>	1	1	3	1	July 7	1	—
<i>Cucurbita maritima</i> .											
74d	July 24	25	Dixie watermelon	Hubbard squash	1	—	3	—	Aug. 8	—	—
74e	July 24	26	Dixie watermelon	Hubbard squash	1	—	3	—	Aug. 8	—	—
89e	Aug. 30	17	Dixie watermelon	Hubbard squash	1	—	3	—	Sept. 5	—	—
74a	July 31	21	Seminole watermelon	Hubbard squash	1	—	3	—	Aug. 13	—	—
74b	July 31	19	Seminole watermelon	Hubbard squash	1	—	3	—	Aug. 13	—	—
84d	Aug. 17	24	Seminole watermelon	Hubbard squash	1	—	3	—	Aug. 21	—	—
88d	Aug. 24	18	Seminole watermelon	Hubbard squash	1	—	3	—	Aug. 30	—	—
120g	1907 Feb. 25	32	Seminole watermelon	Hubbard squash	1	—	3	—	1907 Mar. 4	—	—
128b	Apr. 8	31	Seminole watermelon	Hubbard squash	1	—	3	—	Apr. 20	—	—
76k	1906 Aug. 7	28	Georgia Rattlesnake watermelon	Hubbard squash	1	—	3	—	1906 Aug. 15	—	—
804	Aug. 13	20	Georgia Rattlesnake watermelon	Hubbard squash	1	—	3	—	Aug. 23	—	—
98i	Sept. 10	25	Triumph watermelon	Marblehead squash	1	—	3	—	Sept. 26	—	—
109b	Oct. 10	37	Triumph watermelon	<i>Lagenaria vulgaris</i> , Sugar-Trough gourd	1	—	3	—	Oct. 18	—	—
<i>Cucurbita maritima</i> .											
30l	Aug. 30	13	Red-seeded citron	Hubbard squash	3	—	3	—	Sept. 6	—	—
30a	Sept. 3	17	Red-seeded citron	Hubbard squash	3	—	3	—	Sept. 10	—	—
98d	Sept. 10	24	Red-seeded citron	Marblehead squash	3	—	4	—	Sept. 26	—	—
110f	Oct. 10	29	Red-seeded citron	Marblehead squash	3	—	4	—	Oct. 20	—	—

¹ Leaves only infected.

² Leaves injured by insects

³ One leaf withered.

⁴ Slight infection of one leaf.
⁵ Leaves inoculated first injured by scraping epidermis.

⁶ One leaf well infected. Conidia produced used in experiment 113 on Hubbard squash.

TABLE V.—VARIETIES OF *Citrullus vulgaris* SCHRAD—Continued.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of coinida.	No. of plants used.	No of parts inoc.		No. of controls.	Results.		
						Coty.	Lvs.		Date.	Inoc. pl.	Con- trols.
				<i>Cucurbita maxima</i> .							
125f	1907. Mar. 30	33	Red-seeded citron.	Hubbard squash.....	1	.....	4	1	1907. Apr. 8	++ ⁷	—
128f	Apr. 8	42	Red-seeded citron.....	Hubbard squash.....	1	.....	2	1	Apr. 20	++	—
129c	Apr. 10	39	Red-seeded citron.....	Hubbard squash.....	1	.....	2	1	Apr. 20	++	—
91f	1906. Sept. 3	17	Green-seeded citron.....	Hubbard squash.....	3	.....	3	1	1906. Sept. 10	—	—
97h	Sept. 6	20	Green seeded citron.....	Hubbard squash.....	1	.....	2	1	Sept. 17	—	—
102c	Sept. 17	14	Green-seeded citron.....	Marblehead squash.....	1	4	2	1	Oct. 2	—	—
107g	Oct. 3	30	Green-seeded citron.....	Marblehead s' squash.....	1	.....	2	1	Oct. 13	—	—

⁴ Slight infection of one leaf.⁷ The second leaf on each plant well infected.

Five varieties of watermelons and two of citrons were tested. Infection occurred in only nine out of the thirty trials. No inoculated cotyledons became infected and only thirteen out of the eighty-four leaves showed any indication of the growth of the mildew. In a few cases there was a very vigorous growth of the fungus; in other cases, however, the infection was slight. The conidia used for inoculation were obtained mainly from *Cucurbita maxima*, but in one experiment each they were taken from *Melothria scabra* and *Lagenaria vulgaris*.

In most of the tests, it was the first one or two leaves which were inoculated. In experiment 109b. the inoculated leaves were first injured slightly by removing part of the upper epidermis. This had no effect in favoring infection.

The conidia used for inoculation were obtained mainly from *Cucurbita maxima* in experiment 113, table I, causing full infection.

TABLE VI.—*Coccinea cordifolia* COGN.

No. of exp.	Date.	Age of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date.	Inoc. pl.	Controls.
			<i>Cucurbita maxima</i> .					1906		
69g	July 23	25	Hubbard....	2	.....	4	1	Aug. 2	—	—
			squash.							
71h	July 24	25	Hubbard....	2	.....	4	1	Aug. 8	—	—
			squash.							
76i	Aug. 7	39	Hubbard ...	1	.....	2	1	Aug. 15	—	—
			squash.							
84c	Aug. 20	28	Hubbard....	2	.....	4	1	Aug. 30	—	—
			squash.					1907.		
120d	Feb. 25	32	Hubbard....	2	.....	4	1	Mar. 4	—	—
			squash.							
128h	Apr. 8	72	Hubbard....	1	.....	3	.....	Apr. 20	—	.....
			squash.					1906		
110b	Oct. 10	29	Marblehead.	2	.....	4	1	Oct. 18	—	—
			squash.							
110h	Oct. 10	29	Marblehead.	1	2	2	1	Oct. 18	—	—
			squash.							

In the seed catalogues this plant is usually listed under the name of *Coccinea indica*. No successful infections were obtained with seedlings of it, although twenty-seven leaves and two cotyledons were inoculated in the eight trials. The conidia used in all these experiments were taken from *Cucurbita maxima*.

This cucurbit differs from all the others tested in the marked waxy cuticle on the surface of its leaves, giving them a smooth, shiny appearance. Whether such a structural characteristic is of importance in determining a plant's liability to infection is discussed in another connection.

TABLE VII.—VARIETIES OF *Cucumis Anguria* LINN.

No. of exp.	Date.	Age of plants (days.)	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.	
						Cots.	Lvs.		Date.	Inoc. pl.	Con- trols.
	1906			<i>Cucurbita maxima</i> .						
67i	July 12	17	Small gherkin	Hubbard squash	12	1	3	12	1906 July 23	—
69b	July 23	25	Small gherkin	Hubbard squash	12	1	3	12	Aug. 2	—
74f	July 31	33	Small gherkin	Hubbard squash	12	1	4	12	Aug. 13	—
81i	Aug. 17	25	Small gherkin	Hubbard squash	12	1	4	12	Aug. 24	+
84i	Aug. 20	11	Small gherkin	Hubbard squash	12	1	4	12	Aug. 30	—
88b	Aug. 21	18	Small gherkin	Hubbard squash	12	1	4	12	Sept. 3	2
90g	Aug. 30	17	Small gherkin	Hubbard squash	12	1	4	12	Sept. 6	+
48f	Sept. 10	31	Gooseberry gourd	Marblehead squash	1	1	4	1	Sept. 26	+
105j	Oct. 6	57	Gooseberry gourd	Marblehead squash	1	1	3	1	Oct. 18	+
110d	Oct. 10	34	Gooseberry gourd	Marblehead squash	1	1	4	1	Oct. 18	+
111g	Nov. 5	69	Gooseberry gourd	Hubbard squash	1	1	3	1	Nov. 11	+

¹ One leaf of each plant infected.

² Inoculated leaves injured by insects.

³ Only two leaves infected.

⁴ Only one leaf infected.

Both the small gherkin and the gooseberry gourd, belonging to this species, were tested. Four cotyledons and twenty-six leaves of the former were inoculated, only four leaves becoming infected. On the other hand, out of fourteen leaves of the gooseberry gourd inoculated, eleven became infected. The conidia used in all of these experiments were obtained from *Cucurbita maxima*.

From these results, it is seen that there was a noticeable difference in the susceptibility of these two varieties to the mildew. This was the only case where such a difference in capacity for infection was observed among varieties of one species.

TABLE VIII.—*Cucumis dipsaceus* EHR.

No. of exp.	Date.	Age of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date.	Inoc. pl.	Controls.
			<i>Cucurbita maxima</i> .					1906		
67c	July 12	16	Hubbard squash.	2	4	2	4	July 23	+++ ¹	—
81b	Aug. 17	24	Hubbard squash.	2	.....	6	1	Aug. 24	++ ²	—
84a	Aug. 20	14	Hubbard squash.	3	.....	3	2	Aug. 30	—	—
88m	Aug. 24	18	Hubbard squash.	3	.....	6	2	Aug. 30	++ ²	—
107i	Oct. 3	30	Marblehead squash.	2	.....	6	1	Oct. 13	++ ³	—
108f	Oct. 6	30	Marblehead squash.	2	.....	6	2	Oct. 18	—	—
120e	1907 Feb. 25	32	Hubbard squash.	2	.....	6	1	Mar. 4	++ ⁴	—
128c	April 8	28	Hubbard squash.	2	.....	6	2	Apr. 20	+++	—

¹ Only leaves infected.² One leaf of each plant infected.³ Only one leaf infected.⁴ Fair infection of three leaves.

Eight tests were made with seedlings of the Hedgehog gourd, four cotyledons and forty-one leaves being inoculated with conidia from *Cucurbita maxima*. Seventeen of the leaves became infected. The mildew never developed abundantly on these plants, and did not produce the vigorous growth characteristic of most of the other cucurbits.

TABLE IX.—VARIETIES OF *Cucumis melo* LINN.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of con- trols.	Results.		
						Coty.	Lvs.		Date.	Inoc. pl.	Con- trols.
47b 53a 71f	1906 June 13 June 18 July 24	19 24 36	Osage muskmelon..... Osage muskmelon..... Osage muskmelon.....	<i>Cucurbita maxima</i> . Hubbard squash..... Hubbard squash..... Hubbard squash.....	2 1 1	4 3	1 2 1	3 3	1906 June 23 June 28 Aug. 8	++ ++ ++	— —
	61	22	Osage muskmelon.....	Peerless watermelon.....	2	.....	2	2	July 9	+2	—
	63d 88g 91g	21 14 24	Surprise muskmelon..... Surprise muskmelon..... Surprise muskmelon.....	<i>Cucurbita maxima</i> . Hubbard squash..... Hubbard squash..... Hubbard squash.....	2 1 1 1	4	3 4 3 3	1 2 1 1	July 16 Sept. 3 Sept. 10	— ++ ++	— — —
	125h 126b	25 27	Surprise muskmelon..... Surprise muskmelon.....	Hubbard squash..... Hubbard squash.....	2 2	..... .....	2 3	1 1	1907 Apr. 8 Apr. 10	++ ++ ++	— — —
	68c 69f 84b 88u 97b 107b 108h	1806 July 17 July 23 Aug. 20 Aug. 24 Sept. 6 Sept. 31 Oct. 3 Oct. 6 Oct. 19	18 24 27 18 31 22 25	Defender muskmelon..... Defender muskmelon..... Defender muskmelon..... Defender muskmelon..... Defender muskmelon..... Defender muskmelon..... Defender muskmelon.....	Hubbard squash..... Hubbard squash..... Hubbard squash..... Hubbard squash..... Hubbard squash..... Hubbard squash..... Hubbard squash.....	2 1 2 2 2 2 2	..... ..... ..... ..... ..... ..... .....	3 2 4 2 2 2 2	1 1 2 2 1 2 2	1906 July 27 Aug. 2 Aug. 30 Aug. 30 Sept. 17 Oct. 13 Oct. 18 Oct. 13 Aug. 15 Aug. 21 Aug. 21 Sept. 10	++ ++ — ++ ++ ++ ++ ++ — ++ ++ —

3 Three leaves infected.

2 One leaf infected.

1 Leaves infected, cotyledons dead.

TABLE IX.—VARIETIES OF *Cucumis melo* LINN.—Continued.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of con- trols.	Results.		
						Coty.	Lvs.		Date.	Inoc. pl.	Con- trols.
107k	1906 Oct. 6	22	Winter Pineapple muskmelon.....	Marblehead squash.....	3	.....	3	1	1906 Oct. 13	++ ⁴	+
			Winter Pineapple muskmelon.....	Marblehead squash.....	3	.....	3	1	Oct. 18	+	
11a	Feb. 28	35	Snake cucumber ⁵	Golden Bush squash.....	2	4	2	2	Mar. 7	++ ⁶	—
67f	July 12	11	Snake cucumber.....	Hubbard squash.....	3	1	2	2	July 23	++ ⁶	—
68d	July 17	19	Snake cucumber.....	Hubbard squash.....	3	.....	2	1	July 27	++ ⁶	—
80a	Aug. 13	21	Snake cucumber.....	Hubbard squash.....	3	.....	4	1	Aug. 23	++ ⁶	—
89b	Aug. 30	17	Snake cucumber.....	Hubbard squash.....	3	.....	2	1	Sept. 6	++ ⁶	—
108b	Sept. 27	21	Snake cucumber.....	Hubbard squash.....	3	.....	3	1	Oct. 6	++ ⁶	—
15	Mar. 3	37	Pomegranate melon ⁷	<i>Cucurbita pepo</i>	3	6	.....	3	Mar. 12	++	—
			Pomegranate melon.....	Golden Bush squash.....	3	.....	3	3	Mar. 12	++	
65b	July 9	26	Pomegranate melon.....	<i>Cucurbita metridia</i>	3	.....	3	3	July 23	—	—
65c	July 9	21	Pomegranate melon.....	Hubbard squash.....	3	.....	3	3	July 23	—	—
68c	July 17	25	Pomegranate melon.....	Hubbard squash.....	3	.....	4	1	July 27	+	—
80f	Aug. 17	25	Pomegranate melon.....	Hubbard squash.....	3	.....	4	1	Aug. 21	+	—
81f	Aug. 30	20	Pomegranate melon.....	Hubbard squash.....	3	.....	4	1	Sept. 5	++	—
93f	Sept. 3	27	Pomegranate melon.....	Hubbard squash.....	3	.....	4	1	Sept. 10	++	—
108d	Oct. 6	30	Pomegranate melon.....	Hubbard squash.....	3	.....	6	1	Oct. 18	++ ⁸	—
110g	Oct. 10	34	Pomegranate melon.....	Marblehead squash.....	3	.....	6	1	Oct. 18	++ ⁸	—
119d	1907 Feb. 12	19	Mango melon ⁹	Hubbard squash.....	3	6	3	2	1907 Feb. 25	+ ¹⁰	—
			Mango melon.....	Hubbard squash.....	3	.....	6	1	Mar. 4	+ ¹¹	—
			Mango melon.....	Hubbard squash.....	3	.....	3	1	Apr. 8	++ ¹¹	—
			Mango melon.....	Hubbard squash.....	3	.....	4	1	Apr. 10	++ ¹²	—
			Mango melon.....	Hubbard squash.....	3	.....	6	1	May 18	++ ¹²	—

⁴ A few infected areas also on cotyledons.⁵ This is *Cucumis melo*, var. *flexuosus* Naud.⁶ Leaves only infected, cotyledons dying.⁷ This is *Cucumis melo*, var. *Dudaim* Naud.⁸ Four leaves infected, the others dying.⁹ This is *Cucumis melo*, var. *Chillo*.¹⁰ Cotyledons dead, two leaves infected.¹¹ Two leaves of one plant infected.¹² Three leaves infected.

Six horticultural varieties of muskmelons were tested, seventy-two leaves and eleven cotyledons being inoculated in the twenty-eight different trials. Four cotyledons and thirty-nine leaves became infected. Three cotyledons died before the mildew had time to develop. The conidia used for inoculation were taken largely from *Cucurbita maxima*, but in one experiment each from *Citrullus vulgaris* and *Cucumis sativus*.

In addition to these horticultural varieties, three recognized botanical varieties were also tried. Variety *flexuosus* (*Cucumis flexuosus* Linn.) was tested in six experiments, fifteen leaves and eight cotyledons being inoculated. Eleven leaves became infected, all the cotyledons having died.

The Pomegranate melon, var. *Dudaim* (*Cucumis Dudaim* Linn.=*C. odoratissimus* Moench), was used in nine trials. Forty leaves and cotyledons were inoculated, twenty-two becoming infected.

Five tests were made with the Mango melon, var. *Chito*. Twenty-two leaves were inoculated, sixteen becoming infected. All the inoculated cotyledons died.

TABLE X. — VARIETIES OF *Cucumis sativus* LINN.

No. of exp.	Date.	Age of plant (days).	Plant used as host.	Source of Conidia.	No. of plants used	No. of parts inoc.		No. of controls	Results.	
						Coly.	Lvs.		Date.	Inoc. pl.
	1906									
45	June 5	11	Early Cluster cucumber	<i>Echinocystis lobata</i>	2	4	.....	4	June 11	++
51	June 15	21	Early Cluster cucumber	<i>Cucumis sativus</i> . Early cluster cucumber ²	2	.....	4	1	June 25	++
67a	July 12	17	Japan climbing cucumber	<i>Cucurbita maxima</i> . Hubbard squash	2	4	.....	2	July 23	+
68a	July 17	19	Japan climbing cucumber	Hubbard squash	1	.....	4	2	July 27	++
68b	July 23	25	Japan climbing cucumber	Hubbard squash	1	.....	4	1	Aug. 2	++
71c	July 24	26	Japan climbing cucumber	Hubbard squash	1	.....	4	1	Aug. 8	++
76d	Aug. 7	15	Japan climbing cucumber	Hubbard squash	1	.....	4	1	Aug. 15	++
88i	Aug. 24	14	Japan climbing cucumber	Hubbard squash	1	.....	4	2	Sept. 3	++
88b	Aug. 30	20	Japan climbing cucumber	Hubbard squash	1	.....	4	1	Sept. 5	++
92a	Sept. 3	24	Japan climbing cucumber	<i>Cucumis sativus</i> . Japan climbing cucumber	1	.....	2	1	Sept. 10	—
71c	July 24	25	Emerald cucumber	<i>Cucurbita maxima</i> . Hubbard squash	4	.....	2	1	Aug. 8	++
77c	Aug. 8	15	Emerald cucumber	Hubbard squash	3	.....	3	2	Aug. 15	++
84c	Aug. 20	14	Emerald cucumber	Hubbard squash	3	.....	3	2	Aug. 30	—
88d	Aug. 21	18	Emerald cucumber	Hubbard squash	2	.....	3	2	Sept. 3	++
106i	Sept. 27	16	Emerald cucumber	Marblehead squash	3	.....	3	1	Oct. 6	++
1071	Oct. 3	22	Emerald cucumber	Marblehead squash	3	.....	3	1	Oct. 13	++
70h	Oct. 7	11	Nichols' Medium Green cucumber ..	Hubbard squash	1	.....	2	2	Aug. 15	++
90c	Aug. 30	20	Princess cucumber	Hubbard squash	1	.....	4	1	Sept. 6	++
114c	Nov. 5	31	Giant Para cucumber	Hubbard squash	2	.....	4	1	Nov. 14	++ ³
	1907									
120f	Feb. 25	32	Telegraph cucumber	Hubbard squash	1	.....	3	1	Mar. 4	++
121a	Mar. 4	39	Telegraph cucumber	Hubbard squash	1	.....	3	1	Mar. 13	++
123e	Mar. 20	14	White spine improved cucumber ..	Hubbard squash	1	2	1	1	Mar. 30	++
133	May 7	18	White spine improved cucumber ..	<i>Cucumis sativus</i> . ⁵ White spine improved cucumber ..	3	6	3	1	May 20	++

¹ Three cotyledons infected.² Conidia were taken from the cotyledons of the plants used in experiment 45 and sown on leaves of the same plants.³ A few infected areas on cotyledons.⁴ One leaf turned yellow.⁵ Conidia obtained from infected plants in Horticultural greenhouse.

In the above table, tests are recorded on eight varieties of cucumbers, two of which I had previously experimented with. Sixty-two leaves and sixteen cotyledons were inoculated. The mildew developed on fifty-six leaves and fifteen cotyledons. The conidia were obtained from *Cucurbita maxima*, *Echinocystis lobata*, and *Cucumis sativus*. In experiment 133, the conidia were secured from the infected cucumber vines in the Horticultural greenhouse. The conidia produced on these plants were used to successfully infect the Hubbard squash in experiment 135a (table I).

TABLE XI.—*Cyclanthera exfolens* NAUD.

No. of exp.	Date.	Age of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date.	Inoc. pl.	Controls.
	1906		<i>Cucurbita maxima</i> .					1906		
68k	July 17	19	Hubbard squash.	2	.....	3	1	July 24	++	—
69b	July 22	25	Hubbard squash.	1	.....	4	1	Aug. 2	+++ ¹	—
80b	Aug. 13	21	Hubbard squash.	2	.....	6	1	Aug. 23	— ²	—
90b	Aug. 30	13	Hubbard squash.	3	.....	3	1	Sept. 6	++ ¹	—
91e	Sept. 3	17	Hubbard squash.	2	.....	3	1	Sept. 10	—	—
114c	Nov. 5	31	Hubbard squash.	1	2	5	2	Nov. 14	++ ³	—
115g	Nov. 17	43	Hubbard squash.	2	.....	6	1	Nov. 30	+++ ⁴	—
123a	Mar. 20	18	Hubbard squash.	1	2	1	1	Mar. 30	+++	—
125e	Mar. 30	28	Hubbard squash.	1	.....	4	1	April 8	+ ²	—
98g	Sept. 10	17	Marblehead squash.	2	.....	6	1	Sept. 26	+++ ²	—
103b	Sept. 17	24	Marblehead squash.	1	.....	3	1	Oct. 2	—	—
107j	Oct. 3	30	Marblehead squash.	1	.....	4	1	Oct. 13	—	—
110c	Oct. 10	37	Marblehead squash.	1	.....	5	1	Oct. 18	—	—

¹ Two leaves infected.

² One leaf infected.

³ Four leaves infected.

⁴ Five leaves infected, an infected area on a cotyledon just below an infected leaf.

The squirting cucumber was used in thirteen tests. Out of fifty-three leaves and four cotyledons inoculated, twenty leaves and two cotyledons became infected. The conidia used were taken from *Cucurbita maxima*. While there never was a vigorous growth of the mildew on this host, yet conidia were produced fairly abundantly.

TABLE XII.—*Ecballium elaterium* A. RICH.

No. of exp.	Date.	Age of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date.	Inoc. pl.	Con- trols.
80c	1906 Aug. 13	49	<i>Cucurbita maxima</i> . Hubbard squash.	1	.....	2	.....	1906 Aug. 23	—	.....
97g	Sept. 6	31	Hubbard squash.	1	.....	3	1	Sept. 17	++	—

This cucurbit is sold under the name of *Momordica elaterium*. Only two tests were made with it, five leaves being inoculated. Three of these became well infected and the conidia obtained were used to successfully infect the Hubbard squash in experiment 101 (table I).

TABLE XIII.—*Echinocystis lobata* TORR. AND GRAY.

No. of exp.	Date.	Age of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results		
					Coty.	Lvs.		Date.	Inoc. pl.	Con- trols.
	1906		<i>Lagenaria vulgaris</i> .					1906		
41b	May 14	.....	Dippergourd	1	2	1	.....	May 23	----	.....
41c	May 14	.....	Dippergourd	1	2	.....	.....	May 23	----	.....
46b	June 5	.....	Dippergourd	1	.....	3 ¹	.....	June 15	----	.....
			<i>Cucurbita maxima</i> .							
42b	May 15	.....	Hubbard squash.	1	1	1	.....	May 27	----	.....
43b	May 19	.....	Hubbard squash.	1	1	1	.....	June 5	----	.....
43c	May 19	.....	Hubbard squash.	1	1	2	.....	June 5	----	.....
47a	June 13	.....	Hubbard squash.	1	.....	3 ³	.....	June 18	—	.....
58b	June 23	.....	Hubbard squash.	1	.....	2	.....	July 6	— ⁴	.....
60c	June 28	.....	Hubbard squash.	1	.....	2	.....	July 9	—	.....
60d	June 28	.....	Hubbard squash.	1	.....	2	.....	July 9	—	.....
	1907							1907		
123b	Mar. 20	16	Hubbard squash.	1	2	1	1	Mar. 30	+++	—
125g	Mar. 30	26	Hubbard squash.	1	.....	3 ⁵	1	Apr. 8	-----	—
126c	Apr. 1	28	Hubbard squash.	1	.....	3 ⁵	.....	Apr. 10	+++	.....
128d	Apr. 8	16	Hubbard squash.	1	2	2	1	Apr. 20	+++	—
129d	Apr. 10	18	Hubbard squash.	2	.....	6	1	Apr. 20	+++	—
	1906		<i>Cucumis sativus</i> .					1906		
56	June 23	.....	Early Cluster cucumber.	1	.....	2	.....	July 9	—	.....

¹ The 15th-17th leaves inoculated.

² Leaf only infected, cotyledon yellow.

³ 22nd-24th leaves inoculated; conidia produced sparingly.

⁴ One leaf infected.

⁵ 4th-6th leaves inoculated.

⁶ 6th-8th leaves inoculated.

The plants used in 1906 were obtained out of doors in the spring, brought into the greenhouse and planted in flower pots. Those used in 1907 were grown from seed collected in the fall and planted in flower pots which were left out of doors during the winter. These were then brought into the greenhouse in the early spring before the seeds had germinated. I was unable to get the seed purchased from the seed-stores to germinate.

Altogether sixteen tests were made, thirty-four leaves and eleven cotyledons being inoculated. These were inoculated with conidia from *Cucurbita maxima*, *Cucumis sativus*, and *Lagenaria vulgaris*. Twenty-seven leaves and ten cotyledons became infected. The conidia produced on these plants were used to successfully infect both the Hubbard squash and cucumbers.

TABLE XIV.—VARIETIES OF *Lagenaria vulgaris* SER.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of con- trols.	Results.	
						Coty.	Lvs.		Inoc. pl.	Con- trols.
41a	1906 May 14	.....	Dipper gourd.....	<i>Lagenaria vulgaris</i> . Dipper gourd.....	1	.....	2	.....	1906 May 23	.....
57	June 23	28	Dipper gourd.....	<i>Cucumis melo</i> . Osage muskmelon.....	1	2	1	1	July 6	.....
47a	May 19	40	Dipper gourd.....	<i>Cucurbita maxima</i> . Hubbard squash.....	1	1	4	1	June 5	.....
108c	Oct. 4	41	Dipper gourd.....	Marblehead squash.....	1	.....	3	.....	Oct. 18	.....
81a	Aug. 17	23	Bottle gourd.....	Hubbard squash.....	1	.....	3	.....	Aug. 21	.....
103b	Sept. 17	35	Bottle gourd.....	Marblehead squash.....	1	.....	3	.....	Oct. 2	.....
89i	Aug. 30	14	Spoon gourd.....	Hubbard squash.....	2	.....	12	2	Sept. 13	.....
90j	Aug. 30	11	Spoon gourd.....	Hubbard squash.....	1	.....	5	1	Sept. 6	.....
133a	Sept. 17	18	Spoon gourd.....	Marblehead squash.....	3	.....	4	1	Oct. 2	.....
106c	Sept. 27	28	Spoon gourd.....	Marblehead squash.....	1	.....	2	1	Oct. 6	.....
110i	Oct. 10	29	Spoon gourd.....	<i>Lagenaria vulgaris</i> . Marblehead squash.....	1	.....	4	1	Oct. 18	.....
104a	Oct. 10	29	Spoon gourd.....	<i>Lagenaria vulgaris</i> . Sugar trough gourd.....	2	.....	4	1	Oct. 18	.....
90d	Aug. 30	13	Serpent gourd.....	<i>Cucurbita maxima</i> . Hubbard squash.....	1	2	1	1	Sept. 6	.....
91j	Sept. 3	17	Serpent gourd.....	Hubbard squash.....	1	.....	3	.....	Sept. 10	.....
115a	Nov. 17	43	Serpent gourd.....	Hubbard squash.....	1	.....	3	1	Nov. 30	.....
106h	Sept. 27	35	Serpent trough gourd.....	Marblehead squash.....	1	.....	3	.....	Oct. 6	.....
121c	Mar. 13	48	Sugar trough gourd.....	Hubbard squash.....	1	.....	3	1	1907 Mar. 20	.....
127a	Apr. 6	32	Hercules club gourd.....	<i>Cucumis sativus</i> . Hubbard squash.....	1	.....	2	1	Apr. 15	.....
92b	Sept. 3	17	Hercules club gourd.....	Japan climbing cucumber.....	1	.....	1	.....	1906 Sept. 10	.....

¹ Leaf only infected.² Three leaves infected, infected areas on the underside of two leaves.³ One leaf infected.⁴ Two leaves infected, the others wilted.

In my previous paper I have shown that two varieties of this species, the Bottle and Dipper gourds, can be readily infected by the mildew from the Hubbard squash. In addition to further tests with these two varieties, four others have been tried. In the nineteen experiments here recorded, forty-nine leaves and five cotyledons were inoculated. Thirty-eight of the leaves became infected, while no growth of mildew occurred on the cotyledons. Seedlings of *Cucurbita maxima*, *C. pepo*, *Cucumis sativus*, and *Echinocystis lobata* were all successfully infected with the spores produced on these varieties.

TABLE XV.—SPECIES OF LUFFA.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.	
						Coty.	Lvs.		Date	Inoc. pl.	Con- trols.
	1906			<i>Cucurbita maxima.</i>						
67h	July 12	16	<i>Luffa acutangula</i> Roxby.....	Hubbard squash.....	1	2	1	1	1906 July 23	—
77h	Aug. 8	43	<i>Luffa acutangula</i>	Hubbard squash.....	1	2	1	1	Aug. 15	—
84d	Aug. 20	10	<i>Luffa acutangula</i>	Hubbard squash.....	1	4	1	1	Aug. 30	—
88k	Aug. 24	14	<i>Luffa acutangula</i>	Hubbard squash.....	1	4	1	1	Sept. 3	—
9th	Sept. 3	17	<i>Luffa Aegyptiaca</i> Mill.....	Hubbard squash.....	1	1	1	1	Sept. 10	—
111a	Nov. 3	31	<i>Luffa Aegyptiaca</i>	Hubbard squash.....	1	8	1	1	Nov. 14	—
103f	Sept. 17	31	<i>Luffa Aegyptiaca</i>	Marblehead squash.....	1	6	6	1	Oct. 2	—
106	Sept. 27	28	<i>Luffa Aegyptiaca</i>	Marblehead squash.....	1	6	6	1	Oct. 6	—
107e	Oct. 3	34	<i>Luffa Aegyptiaca</i>	Marblehead squash.....	1	4	1	1	Oct. 13	—
	1907			Hubbard squash.....	1	3	1	1	1907 Apr. 16	—
127c	Apr. 6	63	<i>Luffa Aegyptiaca</i>	Hubbard squash.....	1	...	3	1		—

Seedlings of two species of *Luffa* were tested. Thirteen leaves and cotyledons of *Luffa acutangula* and twenty-nine of *L. aegyptiaca* were inoculated. None of these became infected. It may be noted that the epidermis of these rag gourds is very hard and rough as compared with that of other cucurbits.

 TABLE XVI.—*Melothria scabra* NAUD.

No. of exp.	Date.	Age of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date.	Inoc. pl.	Controls.
	1906							1906		
34a	Apr. 18	34	<i>Cucurbita moschata</i> . Winter Crookneck squash.	3	5	3	3	Apr. 27	+++ ¹	—
38	Apr. 27	43	<i>Cucurbita maxima</i> . Hubbard squash.	2	.....	3	2	May 14	—	—
49	June 13	90	Hubbard squash.	1	.....	3	1	June 25	+++ ²	—
53c	June 18	24	Hubbard squash.	2	4	4	2	June 28	+++ ³	—
60f	June 28	34	Hubbard squash.	1	.....	2	6	July 9	—	—
65d	July 9	45	Hubbard squash.	1	.....	4	3	July 23	—	—
77j	Aug. 8	29	Hubbard squash.	1	.....	3	1	Aug. 15	—	—
50	June 13	90	<i>Cucumis sativus</i> . Early Cluster cucumber.	1	.....	5	1	June 25	+++ ⁴	—

¹ Three cotyledons and two leaves infected.

² Different plants in the same pot were used in experiments 49 and 50.

³ One cotyledon and two leaves infected.

⁴ Three largest leaves infected.

In the eight tests with this species, thirty-six leaves and cotyledons were inoculated, fourteen becoming infected. As in the case of *Cyclanthra exfoliens*, there never was a rich development of mildew on this species. Still conidia were formed fairly abundantly and were able to cause infection on the Hubbard squash and the watermelon.

TABLE XVII.—SPECIES OF MOMORDICA.

No. of exp.	Date.	Age of plants (days).	Plant used as host.	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of con- trols.	Results.		
						Coty.	Lvs.		Date.	Inoc. pl.	Con- trols.
	1906			<i>Cucurbita maxima</i> .	1		2		1906	— 1	.....
67a	July 12	17	<i>Momordica balsamina</i> Linn.....	Hubbard squash.....	1		2		July 23	— 1	.....
68a	July 23	28	<i>Momordica balsamina</i>	Hubbard squash.....	1		2		Aug. 2	— 1	.....
76a	Aug. 7	15	<i>Momordica balsamina</i>	Hubbard squash.....	1		2	1	Aug. 15	+ 1	.....
107d	Oct. 3	30	<i>Momordica charantia</i> Linn.....	Marblehead squash.....	1		5	2	Oct. 13	+ 2	.....

¹ The first pair of leaves inoculated.² The first five leaves inoculated, slight infection of one leaf of the first pair and the third leaf, and a good infection of the fifth.

The balsam apple and the balsam pear were tested only a few times. Out of six leaves of the former which were inoculated two became infected, while the mildew developed on three out of the five inoculated leaves of the latter. The conidia for these tests were taken from *Cucurbita maxima*.

TABLE XVIII.—*Sicyos angulatus* LINN.

No. of exp.	Date.	Age of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date.	Inoc. pl.	Controls.
			<i>Cucurbita maxima</i> .					1906		
58a	1906 June 23	.....	Hubbard squash.	1	.....	4	.....	July 6	— ¹	.....
60e	June 28	.....	Hubbard squash.	1	.....	3	.....	July 9	—	.....
114i	Nov. 5	31	Hubbard squash.	1	2	2	.....	Nov. 14	—	.....
115f	Nov. 17	43	Hubbard squash.	1	2	4	2	Nov. 30	— ²	—
117	Dec. 6	62	Hubbard squash.	1	2	5	.....	Dec. 20	— ³	.....
								1907		
120i	Feb. 25	55	Hubbard squash.	1	2	3	.....	Mar. 4	— ⁴	.....
122a	Mar. 13	71	Hubbard squash.	1	.....	4	.....	Mar. 20	— ⁴	.....
123a	Mar. 30	88	Hubbard squash.	1	1	1	.....	Apr. 12	— ³	.....
127b	Apr. 6	14	Hubbard squash.	1	2	1	2	Apr. 15	— ⁵	—
128a	Apr. 8	16	Hubbard squash.	2	4	2	1	Apr. 20	— ⁵	—
129e	Apr. 10	21	Hubbard squash.	2	.....	4	2	Apr. 20	—	—
129f	Apr. 10	21	Hubbard squash.	2	4	2	1	Apr. 20	— ⁶	—
132c	May 7	40	Hubbard squash.	1	2	1	1	May 20	— ⁵	—
132d	May 7	40	Hubbard squash.	1	2	1	1	May 20	— ⁶	—
134b	May 13	46	Hubbard squash.	1	2	3	1	May 20	— ⁵	—
			<i>Cucumis sativus</i> .							
135b	May 20	53	White spine Imp. cucumber.	1	.....	3	.....	June 1	—	.....
116	1906 Dec. 6	62	<i>Sicyos angulatus</i> .	1	2	4	.....	1906 Dec. 20	— ⁷	.....
136	1907 May 22	.....	<i>Sicyos angulatus</i> .	1	.....	1	.....	June 2	— ⁷	.....

¹ The 23th and 28th leaves inoculated.

² Both cotyledons and three leaves infected.

³ One cotyledon infected.

⁴ One leaf infected.

⁵ Fine infection of cotyledons, slight of leaves.

⁶ No infection of leaves

⁷ A leaf of the plant used in experiment 134b inoculated with conidia from the same.

The first tests with the star cucumber were made with plants which were brought in from out of doors. Young leaves of rather old plants were inoculated, none of which became infected.

In the fall, seed was collected and seedlings were grown during the winter. These plants had much smaller leaves than those used in the spring: they also tended to flower while small and dwarfed. Both leaves and cotyledons of such plants readily became infected when inoculated with conidia from the squash. The conidia produced on these in turn were able to infect other seedlings of this species and also the Hubbard squash.

Seedlings which were grown in the following spring were also tested. These were normal in size and appearance. The mildew developed quite vigorously on the inoculated cotyledons but only slightly, if at all, on the leaves, although young, expanding leaves were inoculated. In experiment 136, a leaf was inoculated with conidia taken from the cotyledons of the same plant, but no infection occurred.

Altogether twenty-seven cotyledons and forty-eight leaves were inoculated. Twenty-six cotyledons and twenty-two leaves became infected, most of the latter only slightly. From these results, it is evident that there is a marked difference between the cotyledons and leaves in their susceptibility to the mildew. No such difference was observed in any other cucurbit.

TABLE XIX.—*Cucurbita maxima* DUCHESNE.

No. of exp.	Date.	Age of plants (days.)	Plant used as host.	Source of conidia.	No. of plants used.		No. of parts inoc.		No. of controls.	Results.	
					Coty.	Lvs.	Coty.	Lvs.		Date.	Inoc. pl.	Con- trols.
29g	1906										
31	Apr. 5	.....	Hubbard squash.....	<i>Aster cordifolius</i>	1	2	.....	.....	1	1906	—
19a	Apr. 11	.....	Hubbard squash.....	<i>Aster cordifolius</i>	1	1	.....	.....	1	Apr. 16	—
26	Mar. 12	19	Hubbard squash.....	<i>Aster laevis</i>	1	2	.....	.....	1	Apr. 18	—
111a	Mar. 20	24	Hubbard squash.....	<i>Aster laevis</i>	1	2	.....	.....	1	Apr. 4	—
66a	Oct. 19	32	Hubbard squash.....	<i>Helianthus annuus</i>	1	2	.....	.....	1	Apr. 4	—
78	July 9	10	Hubbard squash.....	<i>Plantago rugelii</i>	1	1	.....	.....	1	Oct. 31	—
85b	Aug. 8	15	Hubbard squash.....	<i>Plantago rugelii</i>	1	1	.....	.....	1	July 23	—
87	Aug. 20	12	Hubbard squash.....	<i>Plantago rugelii</i>	1	1	.....	.....	1	Aug. 19	—
99a	Aug. 23	15	Hubbard squash.....	<i>Plantago rugelii</i>	1	1	.....	.....	1	Aug. 30	—
101b	Sept. 11	12	Hubbard squash.....	<i>Plantago rugelii</i>	1	1	.....	.....	1	Aug. 30	—
66b	Sept. 17	14	Hubbard squash.....	<i>Plantago rugelii</i>	1	1			1	Oct. 2	—
	July 9	11	Marblehead squash.....	<i>Plantago rugelii</i>	1	2			1	Oct. 2	—
										July 23	—
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¹Different seedlings in the same pot used in experiments 25c and 26.

²A few infected areas on another leaf of the same plant.

³An infected area on one leaf of the control.

The above table gives the results of the tests in which conidia, taken from plants belonging to other families than the Cucurbitaceae, were sown on *Cucurbita maxima*. In four experiments, the conidia were obtained from species of asters. None of the twelve leaves and cotyledons inoculated became infected. In experiments 25c (table I) and 26, different seedlings in the same pot were used. The cotyledons and one leaf of one seedling were inoculated with conidia from the Hubbard squash, while the same parts of another were inoculated with conidia from *Aster laevis*. At the end of fifteen days, the inoculated parts of the first plant were covered with a rich growth of mildew, while on the second plant no infection resulted. The control plant used in this experiment also remained entirely free from mildew.

Conidia from the sunflower infected the Hubbard squash in the one trial made. The conidia were taken from plants which had previously been infected with the squash mildew. This test is not quite conclusive because a few small infected areas were observed on another leaf of this same plant. These areas differed in appearance, however, the mildew occurring only in small isolated patches.

Out of ten leaves of squash plants inoculated with conidia from *Plantago rugelii*, six became infected. In some cases, the conidia used were obtained from plantain plants previously infected with the squash mildew, in others, however, conidia of the mildew occurring in nature on the plantain were taken.

TABLE XX.—*Plantago rugelii* DECAISNE.

No. of exp.	Date.	Source of conidia.	No. leaves inoc.	Results.	
				Date.	Inoc. pl.
	1906	<i>Cucurbita maxima</i> .		1906	
60b	June 28	Hubbard squash.....	2	July 7	+++
64a	July 6	Hubbard squash.....	4	July 16	—
64d	July 6	Hubbard squash.....	1	July 16	++
67d	July 12	Hubbard squash.....	4	July 23	—
68b	July 17	Hubbard squash.....	4	July 27	—
69d	July 23	Hubbard squash.....	2	Aug. 2	—
71b	July 24	Hubbard squash.....	3	Aug. 8	+++
75c	Aug. 7	Hubbard squash.....	3	Aug. 15	— ¹
76b	Aug. 7	Hubbard squash.....	3	Aug. 15	++ ²
76c	Aug. 7	Hubbard squash.....	2	Aug. 15	— ¹
77i	Aug. 8	Hubbard squash.....	2	Aug. 15	— ¹
79	Aug. 8	Hubbard squash.....	3	Aug. 15	—
80f	Aug. 13	Hubbard squash.....	2	Aug. 23	— ¹
82a	Aug. 18	Hubbard squash.....	2	Aug. 30	— ³
88a	Aug. 24	Hubbard squash.....	2	Sept. 3	—
90h	Aug. 30	Hubbard squash.....	4	Sept. 6	—
97k	Sept. 6	Hubbard squash.....	3	Sept. 17	—
100a	Sept. 11	Hubbard squash.....	2	Oct. 2	—
	1907			1907	
123d	Mar. 20	Hubbard squash.....	1	Mar. 30	+++
	1906			1906	
70b	July 24	Marblehead squash.....	3	Aug. 8	—
108c	Oct. 6	Marblehead squash.....	3	Oct. 18	—
85a	Aug. 20	<i>Plantago rugelii</i>	2	Aug. 30	—
99b	Sept. 11	<i>Plantago rugelii</i>	3	Oct. 2	—
104a	Sept. 17	<i>Plantago rugelii</i>	3	Oct. 2	—

¹ Both surfaces of the leaves inoculated.

² Only one leaf infected.

³ Petri dish method.

Out of fifty-four leaves of plantain which were inoculated with conidia taken from squashes, ten became infected. A good vigorous growth of mildew resulted in most of the cases, the conidia thus produced being used to successfully infect the Hubbard and Marblehead squashes. Many of the leaves which were inoculated and which did not become infected were badly eaten by thrips. No infection occurred on such injured leaves of any host. The mildew developed only on the young, vigorously growing, healthy leaves.

The three attempts to infect leaves of plantain with conidia from the same host failed. In some cases the supply of conidia for inoculation was scanty.

TABLE XXI.—*Aster cordifolius* LINN.

No. of exp.	Date.	Source of conidia.	No. of leaves inoc.	Results.	
				Date.	Inoc. pl.
	1906			1906	
18	Mar. 7	<i>Aster cordifolius</i>	1	Mar. 19	+++
20	Mar. 15	<i>Aster cordifolius</i>	1	April 4	+++
22	Mar. 20	<i>Aster cordifolius</i>	1	April 4	+++
29c	Apr. 5	<i>Aster cordifolius</i>	3	Apr. 16	+++
29e	Apr. 5	<i>Aster cordifolius</i>	3	Apr. 16	+++
30	Apr. 11	<i>Aster cordifolius</i>	3	Apr. 18	+++
32a	Apr. 17	<i>Aster cordifolius</i>	3	Apr. 27	+++
32b	Apr. 17	<i>Aster cordifolius</i>	1	Apr. 27	—
12	Feb. 28	<i>Aster laevis</i>	1	Mar. 9	++
16	Mar. 7	<i>Aster laevis</i>	3	Mar. 19	+++
21a	Mar. 15	<i>Aster laevis</i>	3	April 4	+++ ¹
52f	June 15	<i>Aster laevis</i>	3	June 28	—
62d	June 30	<i>Aster laevis</i>	3	July 12	—
	1905			1905	
6c	May 30	<i>Aster sagittifolius</i>	2	June 14	++ ²
	1906			1906	
9b	Feb. 5	<i>Aster sagittifolius</i>	3	Feb. 28	—
10	Feb. 12	<i>Aster sagittifolius</i>	3	Feb. 28	+++
23	Mar. 20	<i>Aster sagittifolius</i>	3	Apr. 4	+++
35c	Apr. 23	<i>Aster sagittifolius</i>	3	May 4	—
		<i>Cucurbita maxima</i>			
13	Feb. 28	Hubbard squash.....	2	Mar. 9	—
25a	Mar. 20	Hubbard squash.....	2	Apr. 4	—

¹ Different leaves of the same plant in experiments 20 and 21a.² Only one leaf infected.TABLE XXII.—*Aster laevis* LINN.

No. of exp.	Date.	Source of conidia.	No. leaves inoc.	Results.	
				Date.	Inoc. pl.
	1906			1906	
36	Apr. 25	<i>Aster cordifolius</i>	3	May 4	++
	1905			1905	
5a	May 17	<i>Aster laevis</i>	2	May 26	++
7b	May 30	<i>Aster laevis</i>	3	June 9	+++ ¹
	1906			1906	
28a	Mar. 23	<i>Aster laevis</i>	3	Apr. 4	— ²
39	May 11	<i>Aster laevis</i>	1	May 23	+++
44a	May 23	<i>Aster laevis</i>	2	June 5	—
52a	June 15	<i>Aster laevis</i>	3	June 28	+++ ³
54d	June 19	<i>Aster laevis</i>	4	June 30	+++
59b	June 23	<i>Aster laevis</i>	3	July 9	—
62e	June 30	<i>Aster laevis</i>	4	July 12	+++ ⁴
	1905			1905	
4b	May 6	<i>Aster sagittifolius</i>	3	May 26	+ ¹
6b	May 30	<i>Aster sagittifolius</i>	3	June 4	++
	1906			1906	
35d	Apr. 23	<i>Aster sagittifolius</i>	2	May 4	+
40	May 11	<i>Aster sagittifolius</i>	2	May 23	+++
27	Mar. 23	<i>Cucurbita maxima</i> —Hubbard squash.....	3	Apr. 4	—

¹ One leaf infected.² Plants in poor condition.³ An uninoculated leaf also infected.⁴ Some uninoculated leaves also infected.

TABLE XXIII.—*Aster sagittifolius* WILLD.

No. of exp	Date.	Source of conidia.	No. leaves inoc.	Results	
				Date.	Inoc. pl.
	1906			1906	
11	Feb. 28	<i>Aster cordifolius</i>	1	Mar. 9	+++
29a	Apr. 5	<i>Aster cordifolius</i>	2	Apr. 16	+ ¹
29f	Apr. 5	<i>Aster cordifolius</i>	4	Apr. 16	+ ¹
	1907			1905	
5b	May 17	<i>Aster laevis</i>	2	May 26	+++
7a	May 30	<i>Aster laevis</i>	2	June 9	—
	1906			1906	
21b	Mar. 15	<i>Aster laevis</i>	4	Apr. 4	— ²
28b	Mar. 23	<i>Aster laevis</i>	3	Apr. 4	+++ ³
44b	May 23	<i>Aster laevis</i>	2	June 5	+++
52b	June 15	<i>Aster laevis</i>	3	June 28	—
54b	June 19	<i>Aster laevis</i>	3	June 30	—
	1905			1905	
2b	May 1	<i>Aster sagittifolius</i>	5	May 26	+ ⁴
4c	May 6	<i>Aster sagittifolius</i>	2	May 26	—
6a	May 30	<i>Aster sagittifolius</i>	2	June 9	+ ⁵
6d	May 30	<i>Aster sagittifolius</i>	3	June 9	+
8a	June 3	<i>Aster sagittifolius</i>	2	June 9	+++
	1906			1906	
9a	Feb. 5	<i>Aster sagittifolius</i>	2	Feb. 18	+
33	Apr. 17	<i>Aster sagittifolius</i>	1	Apr. 27	+
35b	Apr. 23	<i>Aster sagittifolius</i>	2	May 4	— ⁶
	1905			1905	
3c	May 1	<i>Solidago caesia</i>	2	May 8	—

¹ Only one leaf infected.

² Plants in poor condition.

³ One leaf infected, the others dying.

⁴ Three leaves infected.

⁵ An infected area on a lower uninoculated leaf.

⁶ Leaves badly injured by insects.

The above tables give the results of tests with three different species of asters—*Aster cordifolius*, *A. laevis*, and *A. sagittifolius*. The first and last species are closely related, but *A. laevis* differs considerably from the other two. The plants used were dug up out of doors and brought into the greenhouse, young leaves of the plants being inoculated. Seedlings were not used in any of the tests.

As seen from the tables, each one of these species can be infected by the mildew appearing in nature on the others. There is no difference in the susceptibility to infection of these species.

I have already shown that the Hubbard squash (table XIX) cannot be infected with the aster mildew. The converse is also true that these asters cannot be infected with the squash mildew. It is true that the number of tests made is not large and more confirmatory evidence is needed. The one attempt to infect *Aster sagittifolius* with conidia from *Solidago caesia* also failed.

TABLE XXIV.—*Helianthus annuus* LINN.

No. of exp.	Date.	No. of plants (days).	Source of conidia.	No. of plants used.	No. of parts inoc.		No. of controls.	Results.		
					Coty.	Lvs.		Date.	Inoc. pl.	Controls.
	1906		<i>Cucurbita maxima</i> .					1906		
42c	May 15	.....	Hubbard squash.	1	2	4	2	May 27	—	—
65g	July 9	21	Hubbard squash.	1	.....	2	.....	July 23	—	.....
84f	Aug. 20	14	Hubbard squash.	2	.....	4	2	Aug. 30	—	—
86b	Aug. 23	17	Hubbard squash.	2	.....	4	1	Aug. 30	—	—
88f	Aug. 24	18	Hubbard squash.	2	.....	4	2	Sept. 3	— ¹	—
90k	Aug. 30	24	Hubbard squash.	2	.....	8	2	Sept. 15	++ ²	—
115b	Nov. 17	28	Hubbard squash.	2	.....	8	1	Nov. 26	++ ³	—
98b	Sept. 10	17	Marblehead squash.	2	.....	4	2	Sept. 26	+ ⁴	—
108k	Oct. 6	19	Marblehead squash.	3	.....	6	2	Oct. 18	+++ ⁵	—
112b	Oct. 19	33	Marblehead squash.	2	.....	8	1	Oct. 31	++ ⁶	—
105	Sept. 17	24	<i>Helianthus annuus</i> .	1	.....	1	1	Oct. 2	++ ⁷	—
111b	Oct. 19	33	<i>Helianthus annuus</i> .	1	.....	2	1	Oct. 31	++ ⁸	—

¹ The second pair of leaves inoculated.² A good infection of seven leaves; plants tall and slender.³ Three leaves of one plant infected, the other plant wilted.⁴ One leaf infected; an infected area on a cotyledon just below this leaf.⁵ Three leaves of one plant infected, an infected area on a cotyledon also.⁶ Two leaves of one plant infected, the other plant dead.⁷ Conidia obtained from plants used in experiment 90k; a cotyledon also infected.⁸ One leaf infected. Conidia obtained from plant used in experiment 108k.

The first five attempts to infect this host with conidia from the squash failed. Some inoculated leaves in each of the other five tests made were infected. In some of these cases, the plants were taller and more slender than normal plants of the same age. This difference was not noted in all cases, however. The conidia produced were able, in turn, to infect both squash and sunflower seedlings. The mildew occurring in nature on the sunflower was not obtained and consequently its capacity to infect the cucurbits could not be tested.

TABLE XXV.—*Solidago caesia* LINN.

No. of exp.	Date.	Source of conidia.	No. leaves inoc.	Results	
				Date.	Inoc. pi.
	1906			1906	
29b	Apr. 5	<i>Aster coriifolius</i>	2	Apr. 16	—
24	Mar. 20	<i>Aster laevis</i>	2	Apr. 4	—
54c	June 19	<i>Aster laevis</i>	4	June 30	—
	1905			1905	
2c	May 1	<i>Aster sagittifolius</i>	4	May 8	—
8c	June 3	<i>Aster sagittifolius</i>	2	June 15	—
	1906			1906	
35a	Apr. 23	<i>Aster sagittifolius</i>	3	May 4	—
17	Mar. 7	<i>Cucurbita maxima</i> —Hubbard squash.....	3	Mar. 19	—
	1905			1905	
1	Feb. 13	<i>Solidago caesia</i>	8	Feb. 20	—
3a	May 1	<i>Solidago caesia</i>	5	May 8	—

All attempts to infect this goldenrod with the mildew occurring on asters and the squash failed. On the other hand, the two attempts to infect it with conidia from the same species were entirely successful.

GENERAL CONSIDERATIONS

I have brought together all of the results given in the above tables into the following general summary. This summary also includes my results with the cucurbit mildew previously published. This general table shows the number of trials with each species, the source of the conidia, the number of leaves and cotyledons inoculated, the number infected, and also the percentage of infection.

Species used as host.	Source of conidia.	No. of trials	No. leaves inoc.	No. inf.	Per cent. infection.
<i>Aster cordifolius</i>	<i>Aster cordifolius</i>	8	17	16	94
<i>Aster cordifolius</i>	<i>Aster laevis</i>	5	11	6	54
<i>Aster cordifolius</i>	<i>Aster sagittifolius</i>	5	13	6	46
<i>Aster cordifolius</i>	<i>Cucurbita maxima</i>	2	4	0	0
<i>Aster laevis</i>	<i>Aster cordifolius</i>	1	3	3	100
<i>Aster laevis</i>	<i>Aster laevis</i>	9	25	15	60
<i>Aster laevis</i>	<i>Aster sagittifolius</i>	4	10	8	80
<i>Aster laevis</i>	<i>Cucurbita maxima</i>	1	3	0	0
<i>Aster sagittifolius</i>	<i>Aster cordifolius</i>	3	7	3	43
<i>Aster sagittifolius</i>	<i>Aster laevis</i>	7	19	8	42
<i>Aster sagittifolius</i>	<i>Aster sagittifolius</i>	8	19	13	68
<i>Aster sagittifolius</i>	<i>Solidago caesia</i>	1	2	0	0
<i>Citrullus vulgaris</i> ¹	<i>Cucurbita maxima</i>	28	84	14	17
<i>Citrullus vulgaris</i>	<i>Lagenaria vulgaris</i>	1	3	0	0
<i>Citrullus vulgaris</i>	<i>Melothria scabra</i>	1	7	3	43
<i>Coccinea cordifolia</i>	<i>Cucurbita maxima</i>	8	29	0	0
<i>Cucumis anguria</i> ²	<i>Cucurbita maxima</i>	11	44	15	34
<i>Cucumis dipsaceus</i>	<i>Cucurbita maxima</i>	8	45	17	38
<i>Cucumis melo</i> ³	<i>Citrullus vulgaris</i>	1	2	1	50
<i>Cucumis melo</i>	<i>Cucumis sativus</i>	1	2	0	0
<i>Cucumis melo</i>	<i>Cucurbita maxima</i>	44	141	83	59
<i>Cucumis melo</i>	<i>Cucurbita pepo</i>	2	8	8	100
<i>Cucumis sativus</i> ⁴	<i>Cucumis sativus</i>	7	28	26	93
<i>Cucumis sativus</i>	<i>Cucurbita maxima</i>	26	77	73	95
<i>Cucumis sativus</i>	<i>Cucurbita moschata</i>	2	4	4	100
<i>Cucumis sativus</i>	<i>Cucurbita pepo</i>	2	12	12	100
<i>Cucumis sativus</i>	<i>Echinocystis lobata</i>	1	4	3	75
<i>Cucurbita foetidissima</i>	<i>Lagenaria vulgaris</i>	1	2	2	100
<i>Cucurbita maxima</i> ⁵	<i>Cucurbita maxima</i>	4	11	8	73
<i>Cucurbita maxima</i>	<i>Aster cordifolius</i>	2	5	0	0
<i>Cucurbita maxima</i>	<i>Aster laevis</i>	2	7	0	0
<i>Cucurbita maxima</i>	<i>Citrullus vulgaris</i>	1	1	1	100
<i>Cucurbita maxima</i>	<i>Cucumis melo</i>	1	1	1	100
<i>Cucurbita maxima</i>	<i>Cucumis sativus</i>	9	18	16	90
<i>Cucurbita maxima</i>	<i>Cucurbita maxima</i>	68	161	138	86
<i>Cucurbita maxima</i>	<i>Cucurbita moschata</i>	3	4	3	75
<i>Cucurbita maxima</i>	<i>Cucurbita pepo</i>	3	10	10	100
<i>Cucurbita maxima</i>	<i>Echallium elaterium</i>	1	1	1	100
<i>Cucurbita maxima</i>	<i>Echinocystis lobata</i>	1	2	2	100
<i>Cucurbita maxima</i>	<i>Helianthus annuus</i>	1	1	1	100
<i>Cucurbita maxima</i>	<i>Lagenaria vulgaris</i>	6	19	19	100
<i>Cucurbita maxima</i>	<i>Melothria scabra</i>	1	2	1	50
<i>Cucurbita maxima</i>	<i>Plantago rugelii</i>	7	10	6	60
<i>Cucurbita maxima</i>	<i>Sicyos angulatus</i>	2	9	9	100
<i>Cucurbita moschata</i> ⁶	<i>Cucurbita foetidissima</i>	2	2	2	100
<i>Cucurbita moschata</i>	<i>Cucurbita maxima</i>	21	51	45	90
<i>Cucurbita moschata</i>	<i>Cucurbita pepo</i>	2	9	6	66
<i>Cucurbita pepo</i> ⁷	<i>Cucumis sativus</i>	1	4	4	100
<i>Cucurbita pepo</i>	<i>Cucurbita foetidissima</i>	3	5	5	100
<i>Cucurbita pepo</i>	<i>Cucurbita maxima</i>	58	178	169	95
<i>Cucurbita pepo</i>	<i>Cucurbita moschata</i>	3	9	9	100
<i>Cucurbita pepo</i>	<i>Cucurbita pepo</i>	8	25	25	100
<i>Cucurbita pepo</i>	<i>Lagenaria vulgaris</i>	2	7	7	100
<i>Cyclanthera exfoliata</i>	<i>Cucurbita maxima</i>	13	51	22	40
<i>Echallium elaterium</i>	<i>Cucurbita maxima</i>	1	5	0	0
<i>Echinocystis lobata</i>	<i>Cucumis sativus</i>	1	2	0	0
<i>Echinocystis lobata</i>	<i>Cucurbita maxima</i>	12	34	29	85
<i>Echinocystis lobata</i>	<i>Lagenaria vulgaris</i>	3	8	8	100
<i>Helianthus annuus</i>	<i>Cucurbita maxima</i>	10	46	16	35
<i>Helianthus annuus</i>	<i>Helianthus annuus</i>	2	3	2	66

Species used as host.	Source of conidia.	No. of trials	No. leaves inoc.	No. inf.	Per cent. infection.
<i>Lagenaria vulgaris</i> ¹	<i>Cucumis melo</i>	1	3	1	33
<i>Lagenaria vulgaris</i>	<i>Cucumis sativus</i>	2	3	2	66
<i>Lagenaria vulgaris</i>	<i>Cucurbita maxima</i>	15	43	36	84
<i>Lagenaria vulgaris</i>	<i>Cucurbita moschata</i>	2	5	5	100
<i>Lagenaria vulgaris</i>	<i>Cucurbita pepo</i>	3	6	6	100
<i>Lagenaria vulgaris</i>	<i>Lagenaria vulgaris</i>	3	9	7	78
<i>Luffa acutangula</i>	<i>Cucurbita maxima</i>	4	13	0	0
<i>Luffa aegyptiaca</i>	<i>Cucurbita maxima</i>	6	29	0	0
<i>Melothria scabra</i>	<i>Cucumis sativus</i>	1	5	3	60
<i>Melothria scabra</i>	<i>Cucurbita maxima</i>	6	23	6	26
<i>Melothria scabra</i>	<i>Cucurbita moschata</i>	1	8	5	62
<i>Momordica balsamina</i>	<i>Cucurbita maxima</i>	3	6	5	83
<i>Momordica charantia</i>	<i>Cucurbita maxima</i>	1	5	3	60
<i>Plantago rugelii</i>	<i>Cucurbita maxima</i>	21	54	10	18
<i>Plantago rugelii</i>	<i>Plantago rugelii</i>	3	8	0	0
<i>Sicyos angulatus</i>	<i>Cucumis sativus</i>	1	3	0	0
<i>Sicyos angulatus</i>	<i>Cucurbita maxima</i>	15	65	42	65
<i>Sicyos angulatus</i>	<i>Sicyos angulatus</i>	2	7	6	86
<i>Solidago caesia</i>	<i>Aster cordifolius</i>	1	2	0	0
<i>Solidago caesia</i>	<i>Aster laevis</i>	2	6	0	0
<i>Solidago caesia</i>	<i>Aster sagittifolius</i>	3	9	0	0
<i>Solidago caesia</i>	<i>Cucurbita maxima</i>	1	3	0	0
<i>Solidago caesia</i>	<i>Solidago caesia</i>	2	13	13	100

In this summary those leaves and cotyledons which died before infection had time to occur are omitted.

¹ In the various tests seven varieties were used.

² Two varieties tested.

³ Nine varieties of muskmelons tested.

⁴ Twelve varieties of cucumbers tested.

⁵ Twelve varieties of squashes tested.

⁶ Four varieties tested.

⁷ Twenty varieties tested.

⁸ Six varieties tested.

From this summary, it is evident that the same form of the mildew, *Erysiphe cichoracearum* DC., occurs on at least eleven species of the cucurbits, belonging to seven genera, infection occurring in these cases in fifty per cent. or more of the trials. Six other species were also infected, but in a smaller percentage of cases. Only three species, belonging to two genera, *Coccinea cordifolia*, *Luffa acutangula*, and *L. aegyptiaca*, are entirely resistant to the mildew.

So far as I am aware, a mildew has been reported to occur in nature on only three of these twenty species tested, namely, *Cucurbita maxima*, *C. pepo*, and *Cucumis sativus*. This may be due to the fact that perithecia are rarely formed on these hosts

and the conidial stage has not been recorded by observers. It is possible, however, that the mildew does not occur in nature on many of these species.

As a result of my experiments, the following cucurbits must be added to the list of host plants of *Erysiphe cichoracearum* DC.: *Citrullus vulgaris* Schrad., *Cucumis anguria* Linn., *C. dipsaceus* Ehr., *C. Melo* Linn., *C. Melo* var. *Chito* Naud., var. *Dudaim* Naud., var. *flexuosus* Naud., *Cucurbita foetidissima* Kunth., *C. moschata* Duchesne, *Cyclanthera explodens* Naud., *Ecballium elaterium* A. Rich., *Echinocystis lobata* Torr. & Gray, *Lagenaria vulgaris* Ser., *Melothria scabra* Naud., *Momordica balsamina* Linn., *M. charantia* Linn., *Sicyos angulatus* Linn.

It is also plain that the biologic form of *Erysiphe cichoracearum*, occurring on so many cucurbits, is not entirely confined to the species of this one family. Out of fifty-four leaves of *Plantago rugelii*, a species belonging to the Plantaginaceae, which were inoculated, ten became infected. These leaves were well infected, producing conidia abundantly. These experiments were also perfectly safeguarded by controls. Furthermore out of ten leaves of squash seedlings, inoculated with conidia from plantain, six became infected.

While this is a small percentage of infection, yet it may be noted that of eight leaves of plantain inoculated with conidia found in nature on this plant, none became infected. The failure to secure infection in many of these cases was due undoubtedly to the fact that some of the leaves were badly injured by thrips eating away the tissues on the underside of the leaf. I never succeeded in infecting leaves of any sort that were badly eaten by insects. Neger was also unable to infect *P. major* with conidia from the same host. Salmon, on the other hand, succeeded in infecting both *P. major* and *P. media* with conidia from the former.

The sunflower, *Helianthus annuus*, was also infected in thirty-five per cent. of the trials in which conidia from the squash were sown on leaves of seedlings. Sixteen out of forty-six inoculated leaves became infected and produced a good growth of mildew. As noted above, the plants infected, in some cases

at least, were tall and slender; in other cases, however, the seedlings seemed to be entirely normal, the conidia produced being able to infect both squash and normal sunflower seedlings.

I have not so far been able to transfer the cucurbit mildew to asters and goldenrods. The mildew occurring on these in nature, which likewise is considered as belonging to the same species, *Erysiphe cichoraccarum* DC., proved unable to infect the squash. Only a few experiments were made, it is true, and accordingly these results are not entirely conclusive.

It is clear, furthermore, that the same mildew occurs on the three species of asters tested—*Aster cordifolius*, *A. laevis*, and *A. sagittifolius*. Although infection did not take place in every case, yet the mildew from one species would infect plants of the others as readily as plants of the same species.

Neither the aster mildew nor the cucurbit mildew proved able to infect a goldenrod, *Solidago caesia*. Nor was the mildew on this host able to infect asters or squashes. Here again the number of tests is small and further confirmatory evidence is needed.

It should also be noted that seedlings of plantain, asters, and the goldenrod were not tried. While young leaves were generally inoculated, yet these were on old plants. More certain and constant results might be obtained by using seedlings.

For the purpose of further direct comparisons I have brought together in the following summary, all of the results of inoculation experiments with the mildews. Many of these results rest upon inadequate data and additional experiments are required to verify them. In the larger number of cases, the results depend upon only one or two tests.

RESULTS WITH ERYSIPIHE CICHORACEARUM DC.

Conidia from *Artemisia vulgaris*¹ infected *A. vulgaris*, but not *A. absinthium*, *Alchemilla vulgaris*,² *Galium rotundifolium*,² *G. silvaticum*,² *Hieracium murorum*, *Lactuca muralis*, *Leontodon taraxacum*, *Lithospermum arvense*, *Plantago lanceolata*, *Ranunculus repens*,² *Senecio vulgaris*, nor *Sonchus oleraceus*.

¹ Neger (19).

² These plants are not reported as hosts of this mildew.

Conidia from *Hieracium murorum*¹ infected *H. murorum* and *Leontodon taraxacum*,³ but not *Artemisia vulgaris*, *Galium silvaticum*, *Hypericum montanum*, *Lactuca muralis*, nor *Sonchus oleraceus*.

Conidia from *Lactuca muralis*¹ infected *L. muralis*, but not *Galium silvaticum*,² *Hieracium murorum*, nor *Pulmonaria officinalis*.

Conidia from *Lappa major*¹ did not infect *Artemisia vulgaris* nor *Senecio vulgaris*.

Conidia from *Lithospermum arvense*¹ infected *L. arvense*, but not *Hieracium murorum*, *Pulmonaria officinalis*, nor *Symphytum tuberosum*.

Conidia from *Plantago major*¹ did not infect *P. major*, *Artemisia vulgaris*, nor *Hieracium murorum*.

Conidia from *Plantago major*⁴ infected *P. major* and *P. media*, but not *P. lanceolata*, *Eupatorium cannabinum*, nor *Galium aparine*.

Conidia from *Pulmonaria officinalis*⁶ did not infect *Hieracium murorum*.

Conidia from *Senecio vulgaris*⁶ infected *S. vulgaris* and *Lactuca muralis*,⁵ but not *Hieracium murorum*, *Pulmonaria officinalis*, nor *Symphytum tuberosum*.

Conidia from *Verbascum thapsiforme*⁶ did not infect *Artemisia vulgaris*.

RESULTS WITH ERYSIPIHE GALEOPSISIDIS DC.

Conidia from *Galeopsis tetrahit*⁶ infected *G. tetrahit*,⁷ but not *Calamintha acinos*, *Glechoma hederacea*, nor *Stachys recta*.

Conidia from *Ballota nigra*⁴ infected *B. nigra*, but not *Salvia verticillata*, nor *Leonurus cardiaca*.

¹ Neger (19).

² These plants are not reported as hosts of this mildew.

³ On the third day after inoculation, a few conidiophores appeared, but by the following day had disappeared.

⁴ Salmon (29).

⁵ A single small infected area appeared in one experiment.

⁶ Neger (19).

⁷ Infection failed on older plants.

RESULTS WITH ERYSIPIHE GRAMINIS DC.⁸

Conidia from *Agropyron repens*⁹ infected *A. caninum* and *A. tectrum*, but not *A. repens*, *A. acutum*, nor *A. glaucum*.

Conidia from *Avena nuda*¹⁰ infected *A. nuda*, *A. brevis*, and *A. sativa*.

Conidia from *Avena sativa*¹⁰ infected *A. sativa*, *A. brevis*, *A. nuda*, *A. orientalis*, *A. sterilis*, and *A. strigosa*, but not *Alopecurus pratensis*, *Arrhenatherum clatius*, *Dactylis glomerata*, *Festuca heterophylla*, *F. clatior* var. *arundinacea*, *F. clatior* var. *pratensis*, *Hordeum vulgare*, *Lolium italicum*, *Phleum pratense*, *Poa annua*, *Secale cereale*, *Trisetum pratense*, nor *Triticum vulgare*.

Conidia from *Avena sterilis*¹¹ infected *A. pratense*, and *A. sativa*, but not *Arrhenatherum avenaceum*, *Festuca clatior*, *Bromus sterilis*, *B. unioloides*, nor *Lolium temulentum*.

Conidia from *Bromus adocensis*¹² infected *B. adocensis*, *B. hordeaceus*, but not *B. interruptus*, nor *B. mollis*.

Conidia from *Bromus arduennensis*¹² infected *B. adocensis*, *B. hordeaceus*, *B. patulus* and *B. tectorum*, but not *B. commutatus*, *B. Gressoni*, *B. madritensis*, *B. mollis*, *B. sterilis*, nor *B. unioloides*.

Conidia from *Bromus arduennensis* var. *villosus*¹² infected *B. hordeaceus*.

⁸ Marchal (16), although giving no details of his experiments, makes seven specialized forms of the grass mildew as follows:

1. f. spec. Tritici upon *Triticum vulgare*, *T. Spelta*, *T. polonicum*, *T. turgidum*; not on *T. durum*, *T. monococcum*, nor *T. dicoccum*.
2. f. spec. Hordei upon *Hordeum hexastichon*, *H. vulgare*, *H. trifurcatum*, *H. nudum*, *H. jubatum*, and *H. murinum*; not on *H. maritimum*, *H. secalinum*, nor *H. bulbosum*.
3. f. spec. Secalis upon *Secale cereale* and *S. anatolicum*.
4. f. spec. Avenae upon *Avena sativa*, *A. fatua*, *A. orientalis*, and *Arrhenatherum clatius*.
5. f. spec. poae upon *Poa annua*, *P. trivialis*, *P. pratensis*, *P. caesia*, *P. mutabilis*, *P. memorialis* and *P. scrobinia*.
6. f. spec. Agropyri upon *Agropyron*.
7. f. spec. Bromi upon various Bromes.

⁹ Salmon (29).

¹⁰ Salmon (26).

¹¹ Salmon (26).

¹² Salmon (30).

Conidia from *Bromus arvensis*¹² infected *B. arvensis*, but not *B. mollis*.

Conidia from *Bromus commutatus*^{11, 12} infected *B. commutatus*, *B. adoensis*, *B. arduennensis*, *B. arduennensis* var. *villosus*, *B. brizaeformis*, *B. crinitus*, *B. hordeaceus*, *B. Kalmii*, *B. Krausei*, *B. laxus*, *B. marginatus*, *B. patulus*, *B. pungens*, *B. secalinus*, *B. squarrosus*, *B. tectorum*, *B. valdivianus*, and *B. velutinus*, but not *B. angustifolius*, *B. arvensis*, *B. asper*, *B. biebersteinii*, *B. ciliatus* var. *laxus*, *B. erectus*, *B. giganteus*, *B. inermis*, *B. interruptus*, *B. macrostachys*, *B. madritensis*, *B. maximus*, *B. mollis*, *B. mollis* var. *floydianus*, *B. mollis* var. *grossus*, *B. parviflorus*, *B. racemosus*, *B. rigidus*, nor *B. sterilis*.

Conidia from *Bromus hordeaceus*¹³ infected *B. arduennensis*, *B. brizaeformis*, *B. commutatus*, *B. interruptus*, *B. Krausei*, *B. mollis*, *B. secalinus*, *B. tectorum*, and *B. velutinus*, but not *B. arduennensis* var. *villosus*, *B. arvensis*, *B. asper*, *B. crinitus*, *B. erectus*, *B. macrostachys*, *B. madritensis*, *B. madritensis* var. *Delilei*, *B. maximus*, *B. patulus*, *B. racemosus*, nor *B. sterilis*.

Conidia from *Bromus hordeaceus* var. *glabrescens*¹³ infected *B. brizaeformis*, *B. mollis*, and *B. tectorum*, but not *B. arduennensis* var. *villosus*, *B. asper*, *B. giganteus*, nor *B. inermis*.

Conidia from *B. interruptus*¹³ infected *B. interruptus*, *B. brizaeformis*, *B. hordeaceus*, *B. mollis*, *B. tectorum*, and *B. velutinus*, but not *B. arvensis*, *B. asper*, *B. ciliatus*, *B. commutatus*, *B. erectus*, *B. macrostachys*, *B. madritensis*, *B. maximus*, *B. racemosus*, *B. secalinus*, *B. sterilis*, nor *B. unioloides*.

Conidia from *Bromus mollis*¹³ infected *B. mollis* and *B. adoensis*.

Conidia from *Bromus patulus*¹⁴ infected *B. patulus* and *B. hordeaceus*.

Conidia from *Bromus racemosus*^{13, 14} infected *B. racemosus*, *B. adoensis*, *B. arduennensis*, *B. arduennensis* var. *villosus*, *B. commutatus*, *B. hordeaceus*, *B. Krausei*, *B. patulus*, and *B. sec-*

¹¹ Salmon (26).

¹² Salmon (30).

¹³ Salmon (26).

¹⁴ Salmon (30).

alinus, but not *B. ciliatus*, *B. madritensis*, *B. maximus*, *B. squarrosus*, nor *B. tectorum*.

Conidia from *Bromus secalinus*¹⁵ infected *B. secalinus*, *B. adoensis*, *B. arduennensis*, *B. brizaeformis*, *B. commutatus*, *B. condensatus*, *B. crinitus*, *B. fibrosus*, *B. hordeaceus*, *B. Kalmii*, *B. mollis*, *B. patulus*, *B. tectorum* var. *virens*, and *B. velutinus*, but not *B. angustifolius*, *B. Grecsoni*, *B. interruptus*, *B. laxus*, *B. macrostachys*, *B. madritensis* var. *Delilei*, *B. marginatus*, *B. propendens*, *B. pungens*, *B. racemosus*, nor *B. sterilis*.

Conidia from *Bromus tectorum*¹⁶ infected *B. tectorum* and *B. sterilis*.

Conidia from *Bromus velutinus*¹⁵ infected *B. velutinus*, *B. adoensis*, *B. brizaeformis*, *B. hordeaceus*, *B. patulus*, and *B. tectorum*, but not *B. arvensis*, *B. commutatus*, *B. crinitus*, *B. madritensis*, *B. mollis*, nor *B. racemosus*.

Conidia from *Dactylis glomerata*¹⁶ infected *D. glomerata*, but not *Agropyron repens*, *Avena sativa*, *Hordeum vulgare*, *Lolium temulentum*, *Secale cereale*, nor *Triticum vulgare*.

Conidia from *Hordeum decipiens* var. *abyssinicum*¹⁷ infected *H. vulgare*.

Conidia from *Hordeum decipiens* var. *macrolepis*¹⁷ infected *H. vulgare* var. *himalayense*, but not *H. jubatum*.

Conidia from *Hordeum decipiens* var. *steudelii*¹⁷ infected *H. distichum* var. *persicum*, *H. vulgare*, and *H. zeocriton*.

Conidia from *Hordeum distichum* var. *Braunii*¹⁷ infected *H. decipiens* var. *macrolepis*, and *H. vulgare*.

Conidia from *Hordeum distichum* var. *nigricans*¹⁸ infected *H. hexastichon* var. *brachyatherum*.

Conidia from *Hordeum distichum* var. *Rehmii*¹⁸ infected *H. zeocriton*.

Conidia from *Hordeum hexastichon* var. *japonicum*¹⁸ infected *H. distichum* var. *Braunii*, *H. hexastichon* var. *brachyatherum*, *H. intermedium* var. *Hartoni*, and *H. vulgare* var. *coeleste*.

¹⁵ Salmon (30).

¹⁶ Salmon (26).

¹⁷ Salmon (27).

¹⁸ Salmon (27).

Conidia from *Hordeum hexastichon*¹⁸ infected *H. vulgare*, and *H. vulgare* var. *Walpersii*.

Conidia from *Hordeum vulgare*¹⁸ infected *H. vulgare*, *H. vulgare* var. *coeleste*, var. *cornutum*, var. *duplonigrum*, var. *himalayense*, var. *Ciorrhynchum*, var. *nigrum*, var. *trifurcatum*, var. *Walpersii*, var. *violaceum*, *H. bulbosum*, *H. decipiens*, var. *abyssinicum*, var. *deficiens*, var. *macrolepis*, var. *steudelii*, *H. distichum* var. *Braunii*, var. *ianthinum*, var. *medium*, var. *nudum*, var. *Rehmii*, *H. hexastichon*, *H. hexastichon* var. *japonicum*, *H. intermedium* var. *transiens*, *H. maritimum*, *H. zeocriton*, *H. zeocriton* var. *heterolepis*, but not *H. jubatum*, *H. murinum*, *H. secalinum*, *H. silvaticum*, *Avena sativa*, *Secale cereale*, nor *Triticum vulgare*.

Conidia from *Hordeum vulgare* var. *coeleste*¹⁸ infected *H. intermedium* var. *Haxtoni*.

Conidia from *Hordeum vulgare* var. *cornutum*¹⁸ infected *H. distichum* var. *persicum*.

Conidia from *Hordeum vulgare* var. *duplonigrum*¹⁸ infected *H. distichum* var. *nigricans*.

Conidia from *Hordeum vulgare* var. *himalayense*¹⁸ infected *H. decipiens* var. *deficiens*.

Conidia from *Hordeum vulgare* var. *trifurcatum*¹⁹ infected *H. decipiens* var. *steudelii*, *H. distichum* var. *medium*, var. *Rehmii*, and *H. vulgare*.

Conidia from *H. zeocriton* infected *H. distichum* var. *ianthinum*, var. *nudum*, *H. vulgare* var. *cornutum*, var. *himalayense*, var. *Ciorrhynchum*, var. *nigrum*, and var. *violaceum*, but not *H. bulbosum*.

Conidia from *Hordeum zeocriton* var. *heterolepis*¹⁹ infected *H. distichum* var. *nigricans*, and *H. intermedium* var. *transiens*, but not *H. silvaticum*.

Conidia from *Poa pratensis*²⁰ infected *P. pratensis*, *P. annua*, and *P. nemoralis*, but not *Avena sativa*, *Agropyron repens*, *Alopecurus pratensis*, *Dactylis glomerata*, *Festuca arundinacea*,

¹⁸ Salmon (27).

¹⁹ Salmon (27).

²⁰ Salmon (29).

F. elatior var. *pratensis*, *F. heterophylla*, *Hordeum vulgare*, *Lolium perenne*, *L. temulentum*, *Phleum pratense*, *Secale cereale*, nor *Triticum vulgare*.

Conidia from *Poa pratensis*²¹ infected *P. pratensis*, *P. compressa*, *P. nemoralis*, and *P. trivialis*, but not *Avena sativa*, *Bromus mollis*, *Dactylis glomerata*, *Festuca elatior*, *Hordeum jubatum*, *H. vulgare*, *Lolium perenne*, *Phleum pratense*, *Secale cereale*, nor *Triticum vulgare*.

Conidia from *Secale cereale*²¹ infected *S. cereale*, but not *Avena sativa*, *Bromus mollis*, *Dactylis glomerata*, *Festuca elatior*, *F. heterophylla*, *Glyceria fluitans*, *Hordeum jubatum*, *H. vulgare*, *Lolium perenne*, *Phleum pratense*, *Poa pratensis*, *P. compressa*, *P. nemoralis*, *P. trivialis*, nor *Triticum vulgare*.

Conidia from *Triticum vulgare*²² infected *T. vulgare*, *T. Spelta*, and *Hordeum silvaticum*,²³ but not *Avena sativa*, *Agropyron repens*, *Hordeum vulgare*, nor *Secale cereale*.

Ascospores from *Bromus commutatus*²⁴ infected *B. commutatus*, *B. hordeaceus*, but not *B. racemosus*.

Ascospores from *Hordeum vulgare*²⁵ infected *H. vulgare*, *H. trifurcatum*, and *H. zeocriton*, but not *H. bulbosum*, *H. jubatum*, *H. maritimum*, *H. secalinum*, *Avena sativa*, *Secale cereale*, nor *Triticum vulgare*.

Ascospores from *Hordeum vulgare*²⁶ infected *H. vulgare*, *H. distichum*, *H. zeocriton*, and *H. trifurcatum*, but not *Avena sativa*, *Secale cereale*, nor *Triticum vulgare*.

Ascospores from *Secale cereale*²⁶ infected *S. cereale*, but not *Hordeum vulgare*, nor *Triticum vulgare*.

Ascospores from *Triticum vulgare*²⁶ infected *T. vulgare*, but not *Agropyron caninum*, *Avena sativa*, *Hordeum vulgare*, nor *Secale cereale*.

²¹ Reed (21).

²² Salmon (29).

²³ When young plants were used, infection followed; with older plants no infection occurred.

²⁴ Salmon (34).

²⁵ Salmon (25).

²⁶ Marchal (17). No details of the experiments are given.

RESULTS WITH *ERYSIPHE POLYGONI* DC.

Conidia from *Galium silvaticum*²⁷ infected *G. silvaticum*, but not *Aegopodium podagraria*, *Ranunculus repens*, *Senecio vulgaris*, nor *Vicia sepium*.

Conidia from *Heracleum spondylium*²⁷ infected *H. spondylium*, but not *Aegopodium podagraria*, *Anthriscus silvestris*, nor *Hypericum montanum*.

Conidia from *Hypericum perforatum*²⁷ infected *H. perforatum*, and *H. montanum*,²⁸ but not *Galium silvaticum*.

Conidia from *Ranunculus repens*²⁷ infected *R. repens* and *Galium silvaticum*.²⁹

Conidia from *Pisum sativum*³⁰ infected *P. arvense*, but not *Colutea arborescens*, *Onobrychis sativa*, nor *Trifolium pratense*.

Conidia from *Trifolium incarnatum*²⁷ infected *T. incarnatum*, but not *T. repens*, *Galium silvaticum*, *Hypericum montanum*, nor *Vicia sepium*.

Conidia from *Trifolium pratense*³⁰ infected *T. pratense*, but not *T. agrarium*, *T. filiforme*, *T. hybridum*, *T. incarnatum*, *T. medium*, *T. montanum*, *T. repens*, *Lotus corniculatus*, *Medicago sativa*, *Melilotus arvensis*, *Pisum sativum*, nor *Lupinus luteus*.

RESULTS WITH *MICROSPIRA ASTRAGALI*³¹ (DC.) TREV.

Conidia from *Astragalus glycyphyllus*³² infected *A. glycyphyllus* and *A. cicer*, but not *Astragalus* sp., *Vicia sepium*, nor *Robinia pseudoacacia*.

RESULTS WITH *PHYLLACTINIA CORYLEA* (PERS.) KARST.

Conidia from *Corylus avellana*³² did not infect *C. avellana*.

Conidia from *Corylus*³³ infected *Corylus*, but not *Carpinus*.

Conidia from *Carpinus*³³ infected *Carpinus*, but not *Corylus*.

Ascospores from *Carpinus*³³ infected *Carpinus*, but not *Fagus*.

Ascospores from *Fagus*³³ infected *Fagus*, but not *Carpinus*.

²⁷ Neger (19).

²⁸ A slight infection occurred in one case.

²⁹ An infected area present on the under side of one leaf.

³⁰ Salmon (29).

³¹ Neger calls this *Trichoctadia astragali*.

³² Neger (19).

³³ Voglino (38). No details are given.

RESULTS WITH SPHAEROTHECA HUMULI (DC.) BURR.

Conidia from *Potentilla reptans*³⁴ infected *P. reptans*, but not *Agrimonia Eupatoria*, *Alchemilla arvensis*, *A. vulgaris*, *Fragaria* (cult. sp.), *Poterium officinale*, nor *Spiraea ulmaria*.

RESULTS WITH SPHAEROTHECA HUMULI VAR. FULIGINEA (SCHLECHT).

Conidia from *Plantago lanceolata*³⁵ infected *P. lanceolata*, but not *P. major* nor *Taraxacum officinale*.

Conidia from *Taraxacum officinale*³⁵ infected *T. officinale*, but not *Fragaria* (cult. sp.), *Plantago media*, nor *P. lanceolata*.

RESULTS WITH UNCINULA ACERIS (DC.) SACC.

Conidia from *Acer pseudoplatanus*³⁶ infected *A. pseudo-platanus* and *A. campestre*.

RESULTS WITH UNCINULA SALICIS (DC.) WINTER.

Conidia from *Salix purpurea*³⁶ infected *S. purpurea* and *S. caprea*.

Conidia from *Euonymus Japonicus*³⁷ infected *E. Japonicus* var. *aureus* var. *albomarginatus*, var. *ovatus aureus*, var. *microphyllus*, var. *President Gunter*, *E. radicans*, *E. radicans* var. *microphyllus*, and var. *Silver Gem*, but not *E. nanus*, *E. americanus* var. *angustifolius*, *E. chinensis*, *E. europaeus*, *E. radicans* var. *carrierei*, *Celastrus scandens*, *C. articulatus*, *C. orixa*, nor *Prunus laurocerasus* var. *latifolia*.

Taking into account all of the work on the mildews which has been done by Neger, Marchal, Salmon, Voglino and myself, we find that one or more species of five of the genera of the

³⁴ Salmon (29).

³⁵ Salmon (29).

³⁶ Neger (19).

³⁷ Salmon (33). It is not known to what species this mildew belongs. Arcangelii refer it to *Sphaerotheca pannosa*. Salmon, however, regards it as an *Erysiphe* or *Microsphaera*.

Erysiphaceae have been tested for their capacity for infecting hostplants other than the one from which they were obtained. Podosphaera is the only genus which thus far has not been tested. With reference to four genera, Microsphaera, Sphaerotheca, Phyllactinia, and Uncinula, the data are very meager. The bulk of the work has been done with three species of Erysiphe—*E. cichoraccarum*, *E. graminis*, and *E. polygoni* and even with these species the number of trials is very small in many cases, the evidence often resting on a single experiment. Still sufficient data have been accumulated to form the basis of certain, at least tentative general conclusions.

So far as investigated, the mildew on the cucurbits, *Erysiphe cichoraccarum*, is the only one, with the doubtful exceptions recorded by Neger and referred to above, which is shown to be capable of infecting plants belonging to more than one genus. As shown in the tables, my results with this mildew are based on a large number of trials, many of them repeated at different times during three years, and cannot be questioned.

There are other cases where the mildew is limited closely to plants of a single genus. For example, the mildew on rye is limited to species of the genus *Secale*. The same is true with reference to the blue grass mildew on species of *Poa*.

Several cases also are recorded where the mildew from one species will not infect other species of the same genus. Most of these claims, however, rest on insufficient data. The evidence is more conclusive with reference to the mildew on species of *Hordium* and also the one on the Bromo grasses. Salmon (26, 27, 30) has investigated both of these. The mildew on barley, *Hordium vulgare*, will infect this species and also *H. decipiens*, *H. hexastichon*, *H. intermedium*, *H. bulbosum*, *H. distichum*, *H. maritimum*, and *H. zocoriton*, but will not pass over onto *H. jubatum*, *H. murinum*, *H. secalinum*, nor *H. silvaticum*. In some of these cases, however, the number of trials is very small.

Another interesting case is that of the mildew on the Bromes. The following table, slightly modified from the one given by Salmon, (26) shows the results obtained with this mildew.

Source of conidia.		Plants used as hosts.								
		<i>Bromus hor- deaceus.</i>	<i>Bromus mollis.</i>	<i>Bromus inter- ruptus.</i>	<i>Bromus com- mutatus.</i>	<i>Bromus ar- vensis.</i>	<i>Bromus tec- torum.</i>	<i>Bromus ster- ilis.</i>	<i>Bromus sterc- orarius.</i>	<i>Bromus retu- latus.</i>
1	<i>Bromus interruptus</i>	3,3	48,48	10,10	42,0	29,0	16,16	20,0	25,0	26,11
2	<i>Bromus hordeaceus</i> and var. <i>glabrescens</i>		33,33	34,34	47,38	28,0	27,27	13,0	22,9	16,10
3	<i>Bromus commutatus</i>		7,0	9,0	21,21	7,0	18,4	7,0	7,6	7,6
4	<i>Bromus arvensis</i>		9,0			8,8				
5	<i>Bromus tectorum</i>						8,8	8,7		

¹ Subinfection.

The first figure indicates the number of leaves inoculated, the second the number infected.

From his data, Salmon concludes that four, or possibly even five, biologic forms exist within this genus. In looking over his forms, however, there seems to be very little, if any, difference between some of them. The forms on *B. interruptus* and *B. hordeaceus* differ only in their capacity for infecting *B. commutatus*, the mildew on *B. hordeaceus* infecting this host, while that on *B. interruptus* does not. The form on *B. commutatus* differs from that on *B. hordeaceus* in not infecting *B. mollis* and *B. interruptus*. The form on *B. arvensis* infects this same species, but not *B. mollis*. Finally the form on *B. tectorum* differs from that on *B. hordeaceus* in being able to infect *B. sterilis*. It is evident that these biologic forms are not distinctly marked off from one another, even if they exist at all.

Salmon supposes that some of these hostplants, as *B. hordeaceus*, may act as "bridging species," enabling the fungus to pass over from one host to another. For example, the mildew on *B. racemosus* failed to infect *B. commutatus* (twelve trials), while it infected *B. hordeaceus* in one hundred per cent. of the cases (thirty-four trials). Furthermore conidia from *B. commutatus* failed to infect *B. racemosus* (thirty-six trials), while the mildew occurring in nature on *B. hordeaceus* infected *B. commutatus* (forty out of forty-nine trials). From these data, Salmon concludes that *B. hordeaceus* may act as a bridge for

mildews on *B. racemosus* and *B. commutatus*. He tested this in one case by infecting *B. hordaceus* with conidia from *B. racemosus*. The conidia produced on the former were then used to infect *B. commutatus*. Salmon did not test the infecting capacity of the conidia produced on this host in this way. They may have been able to infect both *B. racemosus* and *B. commutatus*, or perhaps only one of these. If only the latter plant should become infected, there would be good evidence that the fungus is modified in its nature by living on the intermediate host.

Specialization of parasitism has been investigated in practically all of the groups of parasitic fungi. As is well known, Eriksson (4, 5) has split the black rust of grasses, *Puccinia graminis* Pers., up into several specialized forms, as follows:—

1. *Puccinia graminis secalis*, on eleven species, belonging to five genera.
2. *Puccinia graminis avenae*, on nineteen species, belonging to thirteen genera.
3. *Puccinia graminis hordei*, on two species, belonging to one genus.
4. *Puccinia graminis agrostis*, on two species, belonging to one genus.
5. *Puccinia graminis poae*, on three species, belonging to one genus.
6. *Puccinia graminis tritici*, on one species, belonging to one genus.

This last form is not sharply marked off, for uredospores from wheat also infect barley, rye and oats in some cases.

Carleton (2), in investigating the specialization of *Puccinia graminis* in this country, has obtained somewhat different results from those of Eriksson. The most striking difference is in Carleton's evidence that the same form occurs on wheat and barley, whereas in Sweden, the form on barley is identical with the one on rye. Furthermore, the form on wheat in this country occurs on thirteen other species of grasses, belonging to eight different genera. Carleton also regards *Hordium murinum* as a host of the form *avenae*, whereas in Sweden, this grass is a

host of the form *secalis*; the form *poae* is also not sharply marked off, for uredospores from *Poa pratensis* infect both barley and oats to a certain extent at least.

Freeman²⁵ more recently has reported that uredospores from barley will infect wheat and rye readily, as well as barley, and oats to a certain extent; uredospores from wheat will infect wheat, rye, and barley, but not oats; uredospores from rye will infect rye, wheat, and barley, but not oats; and, finally, uredospores from oats will infect oats and barley, but not wheat and rye. The oats can be infected by the rust from both wheat and rye by first infecting the barley with uredospores from these hosts, and then sowing the uredospores produced on the barley in this way on the oats.

This work throws considerable doubt upon the existence of distinct biological forms in this species of rust. Further investigations are necessary, not only with the uredospores from various hosts, but also with the other spore forms of the rust. Eriksson, it is true, holds that aecidiospores, produced by teleutospores from a host of one specialized form, will infect only hosts belonging to this form. The aecidial stage, according to his results, does not serve to enable the fungus to infect a larger series of plants: each form is specialized throughout its entire life cycle. If, however, the various forms are not sharply separated from one another in their uredo stage, it is doubtful if they are in their other stages. The whole question is one that needs further thorough investigation.

This same phenomenon of specialization has been described for several other rusts by Eriksson and others. The old *Puccinia sessilis* Schneid., is especially interesting, as a rust in which the uredo and teleuto stages occur on only one host, *Phalaris arundinacea*, while the aecidial stage occurs on a number of monocotyledons. As a result of cultural experiments by Plowright, Winter, Dietel, Klebahn, and others, this species has been found to be specialized as to its aecidial hosts. The following species have been separated out, entirely on the basis of the aecidial host:—

²⁵ Reported at the meeting of Central Botanists, March, 1907.

<i>Puccinia ari-phalaridis</i> ,	aecidium on <i>Arum maculatum</i> .
<i>Puccinia Allii-phalaridis</i>	aecidium on <i>Allium ursinum</i> .
<i>Puccinia smilacearum-digraphidis</i> ,	aecidium on <i>Majanthemum bifolium</i> , <i>Polygonatum multiflorum</i> , <i>Polygonatum verticillatum</i> , <i>Convallaria majalis</i> and <i>Paris quadrifolia</i> .
<i>Puccinia convallariae-digraphidis</i> ,	aecidium on <i>Convallaria majalis</i> .
<i>Puccinia paridi-digraphidis</i> ,	aecidium on <i>Paris quadrifolia</i> .
<i>Puccinia schmidtiana</i> ,	aecidium on <i>Leucjum vernum</i> and <i>Leucjum aestivum</i> .
<i>Puccinia orchidearum-phalaridis</i> ,	aecidium on <i>Orchis maculata</i> , <i>Orchis morio</i> , <i>Orchis latifolia</i> , <i>Platanthera bifolia</i> , <i>Platanthera chlorantha</i> and <i>Listera ovata</i> .

In the Chytridiaceae, Lüdi (13) has tested the infecting capacity of swarmspores of *Synchytrium taraxaci* from *Taraxacum officinale*. He tried to infect nineteen species of Compositae which do not belong to the subdivision Cichoraceae, but with negative results in every case. He also used twenty-one species which belong to genera of this sub-group, but was able to infect only four species of the genus *Taraxacum*:—*T. officinale*, *T. ccratophorum*, *T. palustre*, and *T. erythrospermum*. Three other species of this genus tested, remained free from the fungus. In many of his experiments, Lüdi kept control plants of *T. officinale* and these were readily infected by the swarmspores.

Giesenhagen (10), as a result of his work on the Exoasceae, suggests that *Taphrina aurea*, which infects three species of *Populus*, is becoming specialized into races, each of which is adapted to a single species of *Populus*.

Rostrup (23) believes that the following parasites consist of several distinct biological races, because they are found on different hosts in different regions:—*Dasyscypha Willkommii*, *D. calycina*, *D. abictis*, *Sclerotinia* sp., *Rhytisma acerinum*, *Lophodermium pinastri*, *Phyllachora graminis*, *Epichloe typhina*, *Polystigma rubrum*, *Nectria ditissima*, *Sphacrotheca pannosa*, *Taphrina velutina*, *T. turgida*, *Exobasidium vaccinii*, *Ustilago carbo*, and *Protomyces macrosporus*. Only the smut, *Ustilago carbo*, was tested experimentally.

Magnus (14) mentions, as species having adapted races, *Peronospora parasitica* and *Ustilago violacea*, adapted races of the latter occurring on *Melandryum album*, *Dianthus* sp., and *Malachium aquaticum*.

Stäger (37) has found five physiological species in the ergot of rye, *Claviceps purpurea*. One form occurs on rye and also on seventeen other species of grasses. A second form occurs only on *Glyceria fluitans*; a third is confined to species of *Lolium*; a fourth to *Poa annua*; while the fifth is found on *Brachypodium silvaticum* and *Milium effusum*. Both conidia and ascospores, where tested, are limited in the same fashion.

Stäger did not find any such specialization in *Claviceps microcephala*. This ergot is reported on only three grasses.

There are cases on record, however, in which no tendency to such specialization of parasitism exists. Arthur (1) has been able to infect ten hosts, belonging to three different families, with sponridia from teleutospores of *Puccinia subnitens* Diet., obtained from *Distichlis spicata*.

Eberhart (3) has also found that the swarmspores of *Cystopus candidus* from any one of the following hosts will infect any other:—*Capsella bursa pastoris*, *C. heegeri*, *Lepidium sativum*, *Arabis alpina*, *A. hirsuta*, *A. turrita*, *Iberis amara*, and *Senecioia coronopus*. The swarmspores from *Brassica rapa*, while not tested on any of the plants just mentioned, yet infected *B. rapa*, *B. oleracea*, *B. nigra*, *Sinapis arvensis*, and *Diplotaxis tenuifolia*. Swarmspores of *Cystopus tragopogonis* from *Tragopogon pratensis* infected this plant and also *Scorzonera hispanica*, but no crucifer which was tested.

Camilla Popta (20) has been able to infect a number of umbellifers with the same form of *Protomyces macrosporus*. The following plants were infected with the fungus from *Aegopodium podagraria*:—*Cicuta virosa*, *Scscli montanum*, *Libanotis vulgaris*, *Palimba chalcraii*, *Bubon gemmiferum*, *Pachypleurum alpinum*, *Bunium virescens*, *Ferula thyrsiflora*, *Trinia vulgaris*, *Athamanta cretensis*.

If, now, we study the character of any one host with reference to the specialization of the parasites which attack it, we find no

noticeable correspondence in the behavior of the different fungi. In the parallel columns below are given the hosts of four parasites which attack rye, *Secale cereale*.

<i>Claviceps purpurea.</i>	<i>Erysiphe graminis.</i>	<i>Puccinia graminis.</i>	<i>Puccinia dispersa.</i>
<i>Secale cereale</i>	<i>Secale cereale</i> ...	<i>Secale cereale</i>	<i>Secale cereale</i>
<i>Hordeum vulgare</i>	<i>Secale anatolicum</i> ..	<i>Hordeum vulgare</i>	<i>Hordeum vulgare</i>
<i>Hordeum murinum</i>		<i>Hordeum murinum</i>	<i>Hordeum murinum</i>
<i>Hierchloa borealis</i>		<i>Hordeum jubatum</i>	<i>Hordeum jubatum</i>
<i>Arrhenatherum elatius</i> ..		<i>Hordeum comosum</i> ..	<i>Hordeum comosum</i> ..
<i>Dactylis glomerata</i>		<i>Agropyron caninum</i> ..	<i>Agropyron caninum</i> ..
<i>Festuca pratensis</i>		<i>Agropyron desertorum</i> ..	<i>Agropyron desertorum</i> ..
<i>Phalaris arundinacea</i>		<i>Agropyron repens</i>	<i>Agropyron repens</i>
<i>Briza media</i>		<i>Bromus secalinus</i>	<i>Bromus secalinus</i>
<i>Calamagrostis arundinacea</i> ..		<i>Elymus arenarius</i>	<i>Elymus arenarius</i>
<i>Anthorantherum odoratum</i> ..		<i>Elymus sibiricus</i>	<i>Elymus sibiricus</i>
<i>Poa alpina</i>			
<i>Poa caesia</i>			
<i>Poa compressa</i>			
<i>Poa concinna</i>			
<i>Poa hybrida</i>			
<i>Poa pratensis</i>			
<i>Poa sudetica</i>			

While the mildew and brown rust are limited to the rye, the other two fungi also occur on a number of species, belonging to several different genera. *Hordeum vulgare* and *H. murinum* are hosts of both *Puccinia graminis* and *Claviceps purpurea*. Various species of *Poa* are found as hosts of the ergot of rye, while a distinct form of mildew occurs on this genus.

Nor is there any striking similarity in the specialization of the rust, *Puccinia dispersa*, and the mildew, *Erysiphe graminis*, of the bromes, as worked out by Ward (40, 42) and Freeman (8) for the former, and by Salmon (26, 30) for the latter. The mildew from *Bromus secalinus* infected the following bromes as indicated. Parallel to this are placed the results with uredospores of *P. dispersa* from this brome on the same hosts.

	Conidia of <i>Erysiphe</i> <i>graminis</i> .		Uredospores of <i>Puccinia</i> <i>dispersa</i> .	
<i>Bromus brizaeformis</i>	6*	6	5	3
<i>Bromus commutatus</i>	33	15	9	0
<i>Bromus macrostachys</i>	3	0	5	5
<i>Bromus mollis</i>	6	1	8	3
<i>Bromus racemosus</i>	12	0	12	1

* The first column indicates the number of leaves inoculated, the second, the number infected.

Sufficient data are not available for similar comparisons with the other brome grasses.

From this brief consideration of the specialization in the various groups of parasitic fungi, it is evident that there are, (1) specialized forms which are sharply restricted to definite hostplants, for example, the rye mildew. There are other cases (2) where there is no such sharp limitation to special hosts, but perhaps a tendency for a fungus to infect certain plants much more readily than others, for example, the black rust of cereals. In a third class, the fungus seems able to pass over to a large number of hosts with perfect readiness, as the cucurbit mildew, and also the ergot of rye. Any one host, as rye, may apparently harbor fungi belonging to all three of these classes.

It has been supposed that these physiological forms are the first stages in the evolution of morphological species. This is a very natural idea and occurs to every one, and Fischer (6, 7) has recently brought together fairly good evidence that the various physiological forms in certain rusts are to be considered as stages in the evolution of morphological species. He bases his conclusions on the systematic work of Lindroth (12) and the experimental work of Semadeni (36) on certain rusts of the umbellifers.

Lindroth separates the rusts of this family, on the basis of the characters of the teleutospores, into several groups. In the following scheme, the classification of Lindroth as applied to certain species, and also Semadeni's experimental results with some of these, are given.

Wall of teleutospore smooth—Bullatae.

Pore of under cell near cross wall.

Puccinia libanotidis.

Pore removed from cross wall.

Uredospore with 2-3 germ pores, $22-29\mu \times 21-25\mu$; teleutospore $28-49\mu \times 18-25\mu$.

P. petroselini.

f. sp. on *Aethusa cynapium*.

f. sp. on *Petroselinum sativum*.

Udospores with 3-4 germ pores, $25-40\mu \times 18-23\mu$; teleutospore $28-42\mu \times 18-32\mu$.

P. bullata.

f. sp. on *Silaus pratensis*.

f. sp. on *Thysselinum palustre* (= *Peucedanum palustre*).

Wall of teleutospore reticulated—Reticulatae.

Uredospores with 3 germ pores.

P. chaerophylli

f. sp. on *Chaerophyllum aureum*.

f. sp. on *Anthriscus silvestris*.

Anthriscus cerefolium and on *Myrrhis odorata*.

Uredospores with 2 germ pores.

P. pimpinellae.

Wall of teleutospore warty—Psoradermae.

P. oreosclini.

In this classification, we have the larger groups separated on the basis of the sculpturing of the teleutospore. In the group Bullatae, the next basis of separation is the position of the germ pore of the lower cell of the teleutospore. The species within these subgroups are next separated on the basis of the size and shape of the teleutospore. Further, after all the possible species have been separated on the basis of morphological differences, Semadeni has found, as a result of his experiments, that these morphological species are broken up into physiological forms, sharply restricted to definite hosts. We have here, purely physiological species on the one hand, and widely separated morphological species on the other, with all varying grades of differences between.

This is the most thoroughly worked out attempt to show the connection between these specialized forms and distinct morphological species.

The question arises as to how this specialization has arisen, and it is plain that this leads to the old question of the origin of species. Assuming that species vary, this specialization may have come about in two ways. Either the hostplants may have varied slightly from one another and thus influenced the fungus growing upon them, or the fungus itself may have varied independently of the host.

That changes in the hostplant do influence the parasitism of a fungus, is shown by Salmon's (28, 32) results on injured plants. He has mechanically injured leaves of barley, for example, by cutting away the epidermis on one side of the leaf and also a part of the mesophyll. Conidia taken from wheat were then sown on the intact epidermis of these injured leaves. Salmon found that infection followed, conidia being produced which would infect other similarly injured barley leaves and also normal leaves of wheat, the host from which the fungus was originally obtained. The conidia produced on the barley, however, were not able to infect healthy, uninjured barley leaves. Similar results were obtained when barley leaves were subjected to anaesthetics, alcohol, or water heated to about 50 C., and then inoculated with conidia from wheat.

These experiments show that the hostplant can be made to vary in its ability to resist the attack of the fungus. The immunity which the hostplant naturally enjoys may be destroyed by injury of one sort or another. There is, however, no evidence of any permanent change in the fungus. There is nothing to indicate that it could obtain a permanent foothold on a plant through injuries to the latter, when it cannot infect the same host in its normal condition.

In some of the trials in which I inoculated seedlings of the sunflower with conidia from the squash, the plants were taller and more slender than normal plants of the same age. The conidia produced, however, infected apparently normal sunflower plants as well as squash seedlings.

The age of the hostplant, when inoculated, is also of importance in determining the possibility of infection. Salmon (34) was able to infect young plants of *Hordeum silvaticum* with the mildew from wheat. He cultivated this fungus on *H. silvaticum* for five generations. The conidia produced each time were also tested on wheat, full infection resulting. Thus the mildew did not lose its capacity to infect wheat, nor did it gain the capacity to infect older plants of *Hordeum silvaticum*. Furthermore, it was not able to infect barley, *Hordeum vulgare*, a capacity which the mildew, found in nature on *H. silvaticum*, possesses.

I have obtained somewhat analogous results with the mildew from the squash on *Sicyos angulatus*. As shown in table XVIII, twenty-six of the twenty-seven inoculated cotyledons became infected, while out of forty-eight inoculated leaves, only twenty-two became infected. Furthermore, there never was the vigorous growth of the fungus on the leaves such as occurred on the cotyledons. It is true that the plants used in experiments 115f and 117 were well infected on both leaves and cotyledons. These plants, however, were small and dwarfed as compared with plants in the other tests.

It is also of interest in this connection to note that a plant, when carried to a new region, may become infected by a fungus which is not known to attack it in its native habitat. The white pine in Europe is attacked by *Peridermium Strobi*, a fungus which is not recorded on it in America, the native home of this pine. *Microsphaera alni* is very abundant on *Syringa vulgaris* in North America, while there is no record of the occurrence of this mildew on the lilac in Europe.

The so-called "bridging species" are regarded as of high significance in showing that a parasite may change in its capacity for infecting plants by cultivation on certain hosts. Ward (40) first suggested the idea that certain plants may serve for the passage of a fungus from one host to another, in cases where the fungus on the one plant cannot directly infect the other. He considers *Bromus arduennensis* to be such a bridging species for *Puccinia dispersa*, enabling it to pass from brome species

of the section *Serrafaleus* to species of the section *Libertia*. This brome can be readily infected with uredospores from *B. mollis* of the section *Serrafaleus*, as well as with spores from plants of the section *Libertia*, to which *B. arduennensis* belongs. If we compare Ward's results with spores from these two species on the same hosts, we get the following interesting data:

	Uredospores from <i>B. arduennensis</i> .		Uredospores from <i>B. mollis</i> .	
<i>Libertia</i> .				
<i>Bromus arduennensis</i>	7*	8	14	13
<i>Bromus arduennensis</i> var. <i>villosus</i>	10	10	14	1
<i>Serrafaleus</i> .				
<i>Bromus asper</i>	6	1	41	3
<i>Bromus maximus</i>	6	0	74	1
<i>Bromus mollis</i>	8	1	154	119
<i>Bromus secalinus</i>	8	8	61	31
<i>Bromus sterilis</i>	8	0	148	4

* The first column indicates the number of leaves inoculated, the second the number infected.

I cannot accept Ward's conclusion in this case. From his data, it is evident that the parasites on these two hosts are practically identical in their capacity for infection. Instead of *B. arduennensis* serving as a bridge for the fungus on *B. mollis* to pass over to other bromes, it is, in reality, only a host for the same form of rust as the others. It does not enable the rust on *B. mollis* to pass to any plant which it cannot directly infect.

The evidence that *Bromus krausei* and *B. pendulinus* are "bridging" species is better established. The following data are given to show how these two species may act as "bridges" between *B. sterilis* and *B. mollis*.

	Uredospores from <i>B. sterilis</i> .		Uredospores from <i>B. mollis</i> .	
Serrafalcus.				
<i>Bromus krausei</i>	29*	14	27	27
<i>Bromus pendulinus</i>	65	17	50	50
<i>Bromus molliformis</i>	25	1	26	2
<i>Bromus mollis</i>	137	1	154	119
<i>Bromus vestitus</i>	4	1	4	3
Stenobromus.				
<i>Bromus sterilis</i>	146	126	148	4
<i>Bromus gussoni</i>	60	37	53	6

* The first column indicates the number of leaves inoculated, the second the number infected.

These are the only species which are infected by spores from both *B. mollis* and *B. sterilis*. Of these two, *B. sterilis* and *B. Gussoni*, belong to the section *Stenobromus* and the remainder to the section *Serrafalcus*.

Unfortunately we are not told what the spores on *B. Krausei*, for example, produced by inoculation with spores from *B. mollis* will do. They may infect *B. sterilis* only, or *B. mollis*, or both of these. We need further studies on such forms as these to determine exactly to what extent they may act as bridges, if indeed they act in this capacity at all.

While there are marked differences in the infecting capacity of uredospores from *B. sterilis* and *B. mollis*, yet the two forms can infect each of these species, as well as five others. It seems that the rusts on these two hosts are not sharply marked off from each other. It is possible that here we have races which are adapted to certain hosts, but which can, under favorable conditions, infect several others.

I have already considered the case where barley, according to Freeman, may serve as a bridge for the black rust, *Puccinia graminis*, on rye and wheat to infect oats, and also the case where *Bromus hordeaceus* is supposed to act as a bridging species to enable the mildew on *B. racemosus* to pass on to *B. commutatus*, according to Salmon (31).

In all cases of parasitism the influence of both the parasite and the host must be considered. The external conditions may favor the one or the other. Any external condition which decreases the vitality of the host may favor the increased growth

of the parasite. Lower temperature, increased moisture, too rapid growth, may decrease the host's power of resistance. The factors, on the other hand, which favor the normal development of the host, may lessen the chances of the fungus to develop. These, at least, are the commonly accepted statements as to the relations of pathogenic bacteria to their hosts.

On the other hand, in my work I have observed that experiments often fail if unhealthy plants are used. If the leaves were more or less badly injured by insects, the mildew usually failed to develop, whereas a good infection would result on apparently normal, healthy-looking leaves. It is impossible to say just what difference existed in the host in these two cases, but in general, leaves that were carrying on their normal functions were more susceptible to the mildew than those whose functions were interfered with by insect injury or otherwise.

The resistance of the barley to the rye mildew, and vice versa, may be due either to the anatomical structure of the leaf, or to some influence which the protoplasm of the host exerts, thus hindering or preventing the development of the parasite. In connection with his work on the Brome rust, Ward (41) has investigated very carefully the number and size of the stomata and hairs per square millimetre of surface on both the upper and the lower sides of the leaves, the breadth and thickness of the leaf, the proportions of vascular tissue to chlorophyll tissue, and so forth. He finds no correspondence between any of these measurements and the predisposition or immunity of any species. He concludes that "the capacity for infection or for resistance to infection is independent of the anatomical structure of the leaf and must depend on some other factor or factors in the plant."

I have mentioned above, the fact that the leaves of *Coccinea cordifolia* have a waxy cuticle, and suggested that this might be the reason for the cucurbit mildew failing to establish itself on this plant. Two species of *Luffa* also were entirely resistant to the mildew, and their leaves have a much rougher, harder surface than most other cucurbits. Whether such physical characters may determine the plant's capacity to resist infec-

tion by a fungus, is still a question. In such cases, however, as in the failure of the barley mildew to infect rye, it is hard to see what anatomical characters can prevent infection, especially as the barley can be readily infected by its own mildew.

Massee (18) has recently attempted to explain the parasitism of fungi as due to chemotactic relations. He believes that some substance, perhaps sugar, is present in certain plants, while absent in others. A given fungus is able to attack the former successfully because it is attracted by this substance. "An immune plant is an individual, in which the positive chemotactic substance necessary for facilitating the entrance of the germ tubes of a given parasitic fungus into its tissues, is absent."

This theory fails to explain those cases in which a fungus can get a start in a plant but is not able to complete its development. Salmon (35) has investigated the degree of development of the wheat mildew on barley. He finds that an appressorium is formed by the germ tube and haustoria are formed in the epidermal cells. After forty-eight hours, in most cases, there was no further development. Most of the haustoria had begun to disorganize. By the sixth day, all the haustoria had degenerated more or less completely, while if the wheat mildew had been sown on wheat leaves, full infection, with abundant production of conidia, would have occurred by the sixth day. Similar results were obtained with the oat mildew on wheat, and the mildew from *Bromus mollis* and *B. racemosus* on *B. commutatus*.

In the case of the rusts also, Ward (43) has found that areas of abortive infection are present on even so-called immune plants. The fungus has succeeded in establishing itself but, for one reason or another, has not been able to develop to maturity.

In these cases, the immunity of the host cannot be explained as due to the absence of some positively chemotactic substance in the host. The fungus does affect an entrance and may even nearly reach the stage of spore formation before being checked.

Miss Gibson (9) has sown the spores of several rusts on hosts which they are not known to infect. She has found that in

nearly every case germ tubes were pushed out, which passed through the stomata into the mesophyll of the leaf.

Ward has, in essence, applied the commonly-accepted theory of animal immunity against the bacteria to plants. He says that "infection and resistance to infection depend on the power of the fungus protoplasm to overcome the resistance of the cells of the host by means of enzymes or toxins, and, reciprocally, on that of the protoplasm of the cells of the host to form antibodies which destroy such enzymes or toxins, or to excrete chemotactic substances which repel or attract the fungus protoplasm." The immunity of a host is not due to the inability of the fungus to enter it, but the latter is hindered in its development or from carrying on its normal functions, by the former.

In cases where a fungus successfully attacks a plant, Ward believes that there is some sort of a symbiotic relationship established between the host and parasite. The latter is able to draw upon the resources of the former without interfering with the nutrition and division of the cells of the host. The oat smut thus is able to live in the growing region of the host, and only when the seeds are developing, does the parasite assert itself. It is hard to conceive, however, any advantage which the host derives from this relationship, and by symbiosis we understand the existence of mutualistic relations between organisms, in which there are advantages derived by both plants from their association together.

But there is another and more familiar standpoint from which this matter may be viewed. On the one hand, we have the parasite which is striving to obtain a foothold in the host, in order to secure food for its further development. On the other hand, the host is doing its best to ward off the attack of the parasite and prevent its establishing itself in its tissues. There is then a struggle going on between the two. In those cases where the parasite gains an entrance and produces small abortive infection areas, it is apparently able to overcome, for a time, the defences of the host cells. But the latter soon get the upper hand, and the fungus mycelium is checked in its

growth. Although some cells of the host are killed in this struggle, yet it is a good thing in the end for the host to be thus able to prevent the complete development of the parasite in its tissues.

When, however, a parasite successfully establishes itself, the struggle which has been going on between it and the plant attacked, turns out the other way. The parasite is able to completely overcome the defences of the host and establish itself, passing through its regular life cycle.

On this view, the oat and its smut are not living peaceably together in any sort of symbiosis, but they are constantly engaged in a struggle with each other. The oat has the upper hand for a long time, and manifests no evidence of harboring a parasite in its tissues. When, however, the time for seed formation comes, the young ovule, into which an abundance of rich food is being carried, affords just the right conditions for a vigorous growth of the parasite. It then takes advantage of its opportunities, and forms a mass of spores in the place where the host should form its seed.

It is a question whether, in cases where a parasite gets a start on a host in which it cannot fully develop, the growth of the parasite is inhibited by substances secreted by the host, or whether the former is starved out by the latter. Ward has studied the host cells in the neighborhood of the abortive infection areas on so-called immune plants, as referred to above. He finds that these cells are often collapsed and the nuclei and chromatophores are disintegrated. He concludes that the fungus "hyphae attack the cells too vigorously at the outset. Instead of capturing them, as it were, by putting in haustoria which delicately tap the cell contents and make them serve as sources of food supplies, the fungus clumsily kills these cells and is in consequence subjected to all the exigencies of starvation."

As mentioned above, Miss Gibson (9) has found that a parasite may attain a considerable development in a plant which it finally cannot fully infect. After a period of about three days, the hyphae, which have passed into the interior of the leaf, die

and shrivel up. She believes that the death of the entering hyphae is not due so much to starvation as to some poisonous substance emitted by the host cells, for she has found that, when the hyphae inside the leaf are dead, those on the outside seemed to be normal and full of protoplasm.

We have no definite means of distinguishing between a mycelium killed by poisons and one killed by lack of food. It may be that the barley mildew is unable to get the necessary food material in the rye leaf and so is starved out of existence. It is also possible that, while it can obtain plenty of food material, it also encounters some substance which inhibits its further development. That there is plenty of food in the rye leaf, is proved by the fact that the rye mildew, morphologically like the barley mildew, can develop very vigorously on the leaves of this plant.

The question as to why specialization should be present in some cases and not in others, is raised most clearly by the cases of the grass and cucurbit mildews. The mildew on the grasses is highly specialized, so far as known each specialized form being restricted to species of a single genus. On the other hand, the mildew on the cucurbits is able, not only to infect seventeen species belonging to ten genera of the Cucurbitaceae, but under certain conditions, can also infect the plantain, *Plantago rugelii*, and the sunflower, *Helianthus annuus*, plants which belong to different families from the cucurbits. It is possible that rye and barley are more distantly related to each other than the various genera of cucurbits, but it is hardly likely that these two grains are more distantly related than the squash and plantain. Furthermore, there is certainly no more difference morphologically between *Bromus commutatus* and *B. racemosus* than between the squash, *Cucurbita maxima*, and the cucumber, *Cucumis sativus*.

There is some evidence that differences in habitat may explain, in part, at least, the existence of specialization. Magnus (14) mentions *Ustilago violacea* as infecting one host in one region and another host in another locality. There are, how-

ever, no greater differences in the habitat of the two bromes mentioned, or even of rye and barley, than between the various cucurbits.

There is another phase of the matter that must be considered at least as a possible factor in the explanation. Grasses, in general, have the habit of growing together and forming large meadows, composed of a large number of individuals. These meadows may be almost entirely of one kind of grass, or they may contain a mixture of grasses. It may be that the grass mildew has found it to its advantage to specialize on certain grasses, being able to find always a large number of individuals of any particular host to attack, and by adapting itself to a particular one, is able to attack it more vigorously than it otherwise could.

On the other hand, cucurbit vines usually grow more or less separated from each other. In any particular area there are, as compared with blue grass, relatively few individuals. Now if a fungus was specialized to a particular cucurbit, it would find relatively few individuals to attack, whereas, if it is able to attack any cucurbit in the region, its chances of maintaining itself successfully will be proportionally increased.

It is true, of course, that some cucurbits, as *Sicyos angulatus*, do form rather large colonies of vines in certain localities. They do not, however, compare in number of individuals with the grass colonies in meadows and prairies. No mildew, however, has been reported on this plant, and in my experiments, I never secured a rich infection with normal plants.

In the case of the Compositae, we find that some species form rather large aggregations of individuals. Others have the habit of growing more or less isolated. The plantain often forms areas containing a large number of individuals. This factor of dense aggregations of individuals on the one hand, and their more or less isolated occurrence on the other, is one that needs additional investigation.

It has been suggested that the amount of water in the tissues of a plant, may explain their susceptibility to infection. It is doubtless true that all the cucurbits contain a large amount of

water in their tissues. If, however, we compare barley and rye, there is no marked difference in this respect, and yet each has a mildew sharply restricted to itself. The failure of the barley to be infected by the rye mildew is not due to a lack of water, for its own mildew finds plenty of this in order to obtain a foothold. Some less obvious differences must exist in these two cereals which influence their behavior toward the two parasites.

We are far from being able to lay down any general laws of parasitism. The factors are so complex and the conditions so various that as yet we are not able to state, with any degree of certainty, just why one plant should be infected by a particular parasite and not by another. In all of our investigations, we have not touched upon the fundamental relations that must exist between the cells of the host and parasite, and until we have worked these out, no general laws can be stated.

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Madison, Wisconsin.

Aug. 1. 1907.

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A STUDY OF TELLURIDES

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A STUDY OF TELLURIDES

INTRODUCTION

Sir Humphrey Davy¹, in the course of his investigations upon the alkali metals, prepared the tellurides of potassium and sodium by direct union of the elements, and by the reduction of mixtures of the alkali carbonates and tellurium dioxide with carbon. He describes these substances as alloys of the metals with tellurium, stating that they dissolve in water to deep red solutions and when acidified, yield a gas resembling hydrogen sulphide.

Berzelius prepared and identified hydrogen telluride. He obtained red solutions, similar to those described by Davy, by absorbing hydrogen telluride in solutions of the fixed alkalis, and states that these solutions contain tellurides of the alkali metals analogous to the alkaline sulphides. He also states that hydrogen telluride precipitates insoluble tellurides of the heavy metals from solutions of metallic salts. No analyses of these tellurides are recorded.

Since the time of Berzelius, comparatively little work has been done upon tellurides. The more important contributions to the knowledge of the subject are due to Oppenheim, Margottet, Fabre, Brauner and Hugot. Berthelot and Fabre² in 1888 prepared hydrogen telluride, and the tellurides of the alkali metals both in solution and in the crystalline condition. No analyses of the salts were published.

Eleven years later, Hugot³ prepared the tellurides of sodium

¹ *Phil. Trans. Roy. Soc.*, **27**: 16. (1810).

² *An. Ch. Ph.*, [6] **14**: 104. (1888).

³ *C. R.*, **129**: 299. (1899).

and potassium by the action of tellurium upon the alkali ammoniums in liquid ammonia. They were analyzed and the formulas R_2Te and R_2Te_3 assigned to them.

The tellurides of the heavy metals have been prepared in the dry way only, either by direct union of the elements in an inert atmosphere, or by the reduction of the tellurites. Margottet prepared a number of these compounds, while Fabre repeated and made additions to his work in the course of a thermal study of them.

The alkali tellurides are very unstable, being immediately decomposed by air contact with the liberation of tellurium. This property makes it necessary that all work with their solutions be carried on in an atmosphere from which oxygen is excluded.

It is probable that the instability of these tellurides accounts for the lack of exact knowledge as to their composition and their reactions in the wet way.

MATERIALS

The tellurium used in this work was obtained from the Baltimore Copper Rolling and Smelting Company, having been extracted from electrolytic slimes. It contained small quantities of copper, iron, antimony and selenium as its principle impurities.

It was purified by the following method: the crude tellurium was dissolved in *aqua regia* and reprecipitated as element from hydrochloric acid solution by addition of acid sodium sulphite. The precipitated tellurium was fused at a low red heat with potassium cyanide to remove antimony, the fusion was dissolved in hot water, and, after filtering, the tellurium precipitated by means of a current of air. The sulphur and selenium remained in solution. The tellurium so obtained was dissolved in nitric acid and crystallized twice from dilute nitric acid solution as the basic nitrate. The basic nitrate was ignited and fused to the dioxide, the dioxide dissolved in hydrochloric acid, and the element precipitated by the addition of acid sodium sulphite.

The flocculent precipitate was washed, filtered and dried, and finally fused in an atmosphere of hydrogen.

The dioxide was pure white in color, and yielded upon analysis, by the method⁴ used throughout this work. 79.91% of tellurium.

Data:

0.2008 gm. of TeO_2 gave 0.1604 gm. Te = 79.91%

By calculation, Te^* in TeO_2 = 79.99%

⁴ Lenher and Homberger. *J. A. C. S.*, **30**: 378. (1908).

* The figure 127.6 has been used as the atomic weight of tellurium.

PART I

THE ALKALINE TELLURIDES

SODIUM TELLURIDE

Davy¹ describes the alkaline tellurides as alloys varying from steel grey to copper color, stating that they dissolve in water to red solutions which are decomposed by the oxygen of the air with the precipitation of tellurium, and by hydrochloric acid with the formation of hydrogen telluride gas and common salt.

Berzelius prepared them in a similar manner, and also by solution of hydrogen telluride in solutions of the caustic alkalis.

Bineau² prepared the alkaline tellurides by the action of tellurium upon the alkali amalgams.

Demareay³ advanced the view that the red color of telluride solutions was due either to the presence of polytellurides or to subsalts of tellurium, probably the latter. He gives no analytical data.

According to Berthelot and Fabre,⁴ hydrogen telluride, when absorbed by solutions of the caustic alkalis in the entire absence of air, gives colorless solutions which yield upon evaporation, white or colorless crystalline tellurides. No analyses of these tellurides are recorded. The colorless solutions are immediately rendered pink by the presence of traces of oxygen, the color deepening as the amount of oxygen is increased, tellurium finally separating out as a black precipitate.

¹ *Phil. Trans. Roy. Soc.*, **27**: 16. (1810).

² *An. Ch. Ph.*, [2] **67**: 232. (1863).

³ *Bul. Soc. Chim.*, [2] **40**: 99. (1883).

⁴ *An. Ch. Ph.*, [6] **14**: 104. (1888).

Hugot⁵ describes Na_2Te as a greyish white amorphous powder, soluble in water to a colorless solution which immediately turns pink in the presence of air. Na_2Te_3 is described as soluble in liquid ammonia, separating from that solvent as colorless crystals. The potassium tellurides are entirely similar to those of sodium.

EXPERIMENTAL

Normal sodium telluride, Na_2Te , hydrated, has been prepared as a colorless substance beautifully crystallized, in the following manner:

Experiment 1

Sodium and tellurium were united by heating in an atmosphere of hydrogen. The resulting mass was dissolved in water, the solution filtered and evaporated to crystallization in an atmosphere of hydrogen.

Sodium and tellurium unite at about 250°C with explosive violence.

The reaction was carried out in a Rose crucible placed inside of a large porcelain crucible and heated by the Bunsen flame. Equivalent proportions of sodium and tellurium were taken and when the two elements had united the temperature of the crucible was raised to expel any excess of uncombined sodium or tellurium. A fairly rapid stream of hydrogen was passed into the crucible throughout the experiment, and until the crucible and its contents had cooled. The telluride thus prepared is bronze colored, hard, and shows a crystalline fracture. It is fairly stable in dry air.

In order to obtain a solution of this telluride out of air contact it was quickly transferred to the filtering vessel (A) of the apparatus shown in Plate I. This vessel had a perforated bottom carrying a paper filter. All air in the entire apparatus was displaced by hydrogen from the two generators, the gas

⁵ C. R., 129: 299. (1899).

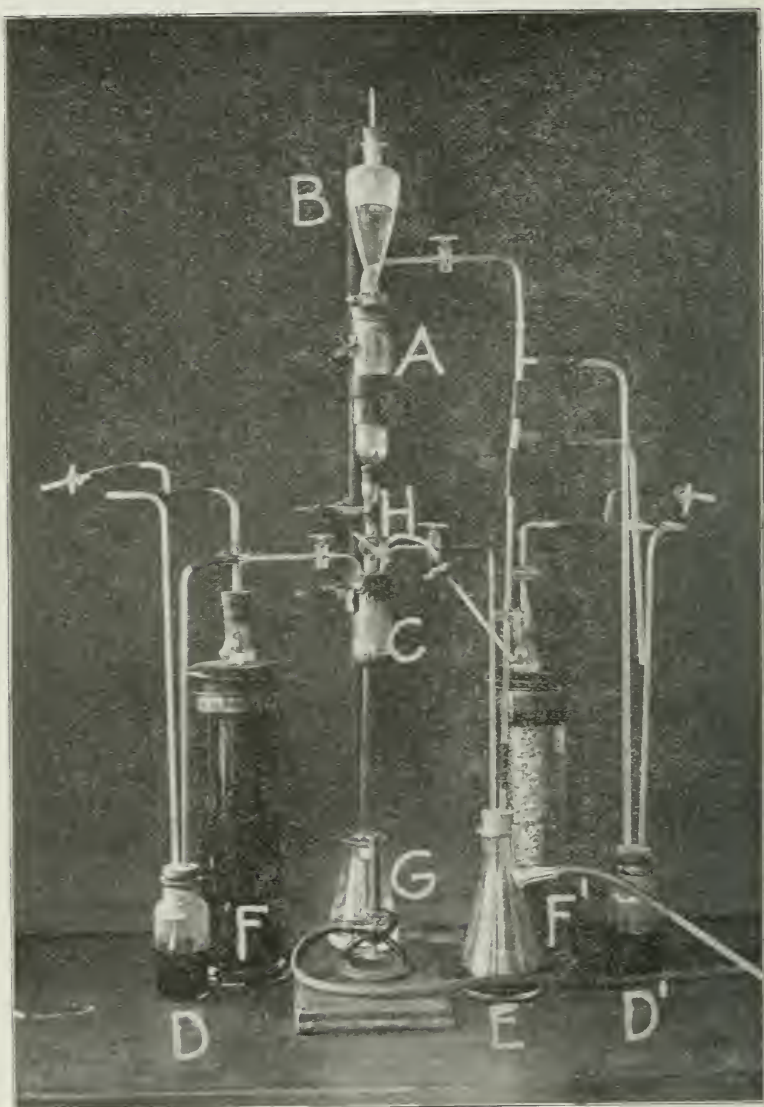


PLATE I.

leaving the apparatus through the mercury seal (E). The inlets and outlets for the gas were so arranged as to allow of perfect displacement of air by hydrogen. The hydrogen from the generators was passed through alkaline pyrogallie acid solution (D-D') to free it from any oxygen that it might contain.

When the apparatus was entirely freed of air, hot water from which dissolved air had been completely removed by boiling, was introduced into the funnel (B) from whence it was allowed to run into (A) where it dissolved the telluride from the filter. The solution, which was at first colored deep red, was run into the flask (G) by means of the three-way stop-cock (H) until it was light pink in color, when it was allowed to flow into the crystallizing flask (C).

The solution was evaporated to small bulk by applying the flame to (C). Hydrogen was bubbled slowly through the solution during the evaporation and passed off with the steam through the mercury seal at (E). From the concentrated solution so obtained, normal sodium telluride separates out upon standing a few hours as colorless, needle-like crystals often half an inch in length. These crystals are highly hydrated at the ordinary temperature and dissolve in their own water of crystallization at about forty degrees.

On account of the extreme instability and the highly hydrated condition of these crystals, they were analyzed and their composition established by determining their sodium-tellurium ratio.

The crystals were drained from the pink mother liquor by disconnecting the crystallizing flask from the filtering vessel and inverting it. It was left thus for several hours, after which a rapid stream of hydrogen was passed through the flask, the stopper removed and the crystals washed with cold water from a wash bottle. When the crystals were perfectly white, they were transferred into a beaker and the tellurium and sodium determined.

METHOD OF ANALYSIS

The determinations of tellurium were made according to the method of Lenher and Homberger⁶ as modified to suit the case in hand.

The solution of alkaline telluride obtained as above was boiled in a Jena beaker in contact with air until the telluride was decomposed as indicated by the disappearance of the red color. Hydrochloric acid was then added to the extent of ten per cent. of the solution, followed by ten cubic centimeters of a saturated solution of sulphur dioxide, ten cubic centimeters of a fifteen per cent. solution of hydrazine hydrochloride, and finally, twenty-five cubic centimeters of sulphur dioxide solution. The whole was boiled for five minutes and the tellurium brought on a tared Gooch filter, washed with hot water and then with alcohol, dried at 100°–105° and weighed. The tellurium so obtained appears as a granular precipitate which settles readily and is easily washed.

The solution from the tellurium determination was evaporated in a tared platinum dish with sulphuric acid, the residue ignited, and weighed as sodium sulphate. In several cases the weight of the sulphate was checked by determining the SO_4 as barium sulphate.

Data:

Te	0.2200 gm.
Na_2SO_4 0.2482 gm. equivalent to Na	0.0805 gm.
Ratio	127.6 : 46.6

Experiment 2

This differed from experiment 1 in that the tellurium was heated with twice the quantity of sodium. Large colorless crystals of hydrated Na_2Te were obtained on crystallization from water.

⁶J. A. C. S., 30: 387. (1908).

Data:

Te	0.1692 gm.
Na ₂ SO ₄ 0.1893 gm. equivalent to Na	0.0612 gm.
Ratio	127.6 : 46.15

Experiment 3

This was similar to experiment 1 except that the sodium-tellurium fusion was heated more strongly and for a longer time. Large colorless crystals of normal telluride were obtained.

Data:

Te	0.3308 gm.
Na ₂ SO ₄ 0.3669 gm. equivalent to Na ...	0.1190 gm.
Ratio	127.6 : 45.90

Normal sodium telluride, highly hydrated, is formed in the crystalline condition from aqueous solution when solutions of sodium-tellurium fusions are evaporated in the absence of air. The presence in the fusion of an excess of sodium does not affect the formation of normal telluride.

The red or permanganate color of alkaline telluride solutions has been ascribed⁷ to the presence of polytellurides or solutions of tellurium in the normal telluride solution.

When sodium and tellurium are united in an atmosphere of hydrogen, and the tellurium is present in large excess over that which would give the normal telluride, a metallic looking crystalline substance is formed which presents the appearance of fused tellurium. It is much more brittle than the element.

This substance, when treated with water in the absence of air, yields a dark red solution and a residue of tellurium. Upon evaporation, the solution yields crystals of the characteristic appearance of the crystals of normal telluride stained red by the dark colored mother liquor. These crystals, on washing with water, become colorless and upon analysis show the composition of the normal telluride.

⁷ Demarcay, *Bul. Soc. Chim.*, [2] 40:99. (1883).

Data:

Te	0.1599 gm.
Na ₂ SO ₄ 0.1754 gm. equivalent to Na ...	0.0569 gm.
Ratio	127.6 : 45.4

When a very large excess of tellurium is used in the preparation of the telluride, the solution upon evaporation and crystallization yields not only Na₂Te crystals, but crystalline elementary tellurium as well.

The mother liquor upon analysis shows sodium and tellurium to be present in such a ratio as to indicate the existence in solution of a telluride having the composition Na₄Te₃, the only telluride other than Na₂Te which has been obtained in aqueous solution. It can not be crystallized, and upon evaporation its solution yields colorless crystals of Na₂Te and crystalline tellurium.

Data:

Te	0.7681 gm.
Na ₂ SO ₄ 0.5711 gm. equivalent to Na ...	0.1854 gm.
which corresponds to the formula Na ₄ Te ₃ .	

That normal sodium telluride will not dissolve tellurium beyond the point represented by the formula Na₄Te₃ has been shown in the following manner: Normal sodium telluride was prepared by the union of equivalent quantities of the elements, dissolved, and filtered into the crystallizing flask which contained a large excess of moist, freshly precipitated tellurium. The solution was boiled with this tellurium for ten minutes and allowed to stand over night, when the undissolved tellurium, of which a large excess remained, settled, leaving the supernatant liquid clear. The sodium-tellurium ratio was determined in this clear solution.

Data:

Te	0.2610 gm.
Na ₂ SO ₄ 0.1889 gm. equivalent to Na ...	0.0613 gm.
Corresponding to the formula Na ₄ Te ₃ .	

It is of interest to note that the polytelluride Na_2Te_3 of Hugot⁸ formed from sodammon and tellurium in liquid ammonia does not form in aqueous solution, and that normal sodium telluride has but a slight solvent action upon tellurium as compared with the solubility of sulphur in sodium sulphide.

POTASSIUM TELLURIDE

Elementary tellurium and metallic potassium combine violently at 250° , the union being much more energetic than that of tellurium and sodium.

In order to ascertain the temperature at which the union of potassium and tellurium takes place, the Rose crucible in which the reaction is brought about was placed in an asbestos-covered sheet iron air bath. Heat was applied and the temperature was taken at intervals of three to five degrees. At 253° there was a sharp explosion.

The telluride formed is of a dark iridescent purple color, with a metallic lustre when freshly broken. It is crystalline in structure and dissolves in water to a purple solution, which upon evaporation does not yield crystals but forms a thick syrupy liquid. From this thick liquid alcohol precipitates small indistinct crystals. The crystals, after washing several times by decantation with alcohol, were analyzed.

As in the case of normal sodium telluride, normal potassium telluride is formed whether the amount of potassium used in the preparation is equivalent to that required for the normal telluride or whether it is in large excess.

Aqueous potassium telluride is even more unstable on exposure to air than the corresponding sodium telluride solution. It was never obtained colorless.

⁸ *C. R.*, **129**: 299. (1899).

EXPERIMENTAL

Experiment 1

Equivalent proportions of tellurium and potassium corresponding to K_2Te were united. The crystals precipitated from aqueous solution by alcohol gave the following result:

Data:

Te	0.0947 gm.
K_2SO_4 0.1273 gm. equivalent to K	0.0571 gm.
Ratio	127.6 : 76.9

Experiment 2

To the normal telluride formed in fusion, a large excess of potassium was added and the whole heated for twenty minutes at a red heat. The crystals obtained as in experiment 1 gave the following:

Data:

Te	0.1040 gm.
K_2SO_4 0.1451 gm. equivalent to K	0.0652 gm.
Ratio	127.6 : 80.00

PART II

TELLURIDES OF THE HEAVY METALS

A number of metallic tellurides have been obtained by double decomposition between metallic salts and sodium telluride in aqueous solution. When normal sodium telluride is employed, normal tellurides either hydrated or anhydrous are formed. The dark red solution of the polytelluride Na_4Te_3 , on the other hand, precipitates metallic tellurides of corresponding composition.

In the preparation of the metallic tellurides the same apparatus was employed as in the preparation of the alkaline tellurides, modified somewhat to suit the changed conditions.

A wide-mouthed Erlenmeyer flask of 400 cc. capacity was substituted for the 100 cc. crystallizing flask shown in Plate I. This flask contained the freshly boiled solution of the metallic salt. Sodium telluride solution was prepared in the usual way and introduced into the precipitating flask.

The tellurides of the heavy metals are thrown down as heavy amorphous precipitates which are granular and settle readily.

The solutions of the metals employed must be of such character as would dissolve any metallic hydrate formed by traces of sodium hydroxide in the telluride solution, but which, on the other hand, would be without action upon the telluride after it is precipitated. For the most part, solutions of metallic acetates acid with acetic acid were found to be best.

On account of the ready oxidation of some of the tellurides when in the moist condition, it was necessary to wash, filter and dry the precipitates out of air contact. This was accomplished as follows: the precipitated telluride was allowed to settle and the supernatant liquid, which always contained an

excess of metallic salt, was transferred into a filtering flask, and the precipitate washed by decantation with hot, freshly-boiled water until free from dissolved salt. The precipitate was then filtered by means of a Gooch filter in hydrogen, dried as far as possible by suction, and further dried by passing over it a current of hot hydrogen, after which it was transferred to a vac-

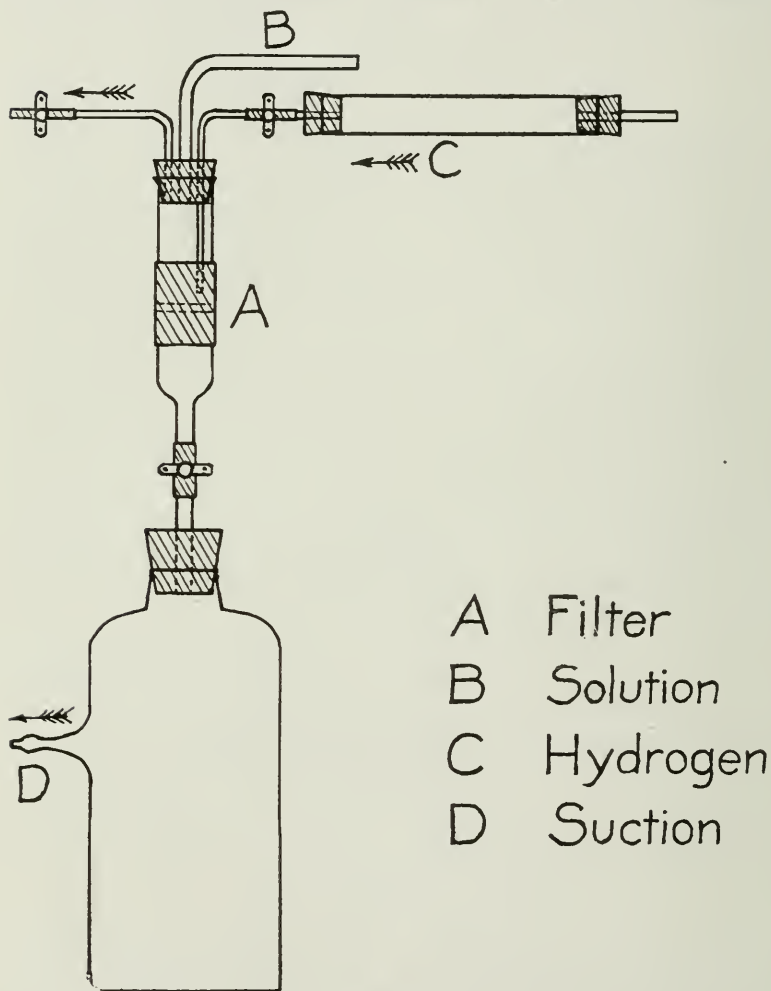


Fig. 1.

uum dessicator containing phosphorus pentoxide. When dry, the tellurides are stable in the air. Even with the great precautions taken in the preparation of the tellurides, it was in some cases almost impossible to prevent small quantities of tellurium from contaminating the precipitates.

The apparatus for filtering and drying in hydrogen is shown in detail in Fig. 1.

TELLURIDE OF ZINC

Margottet¹ describes this substance as an amorphous grey powder obtained by direct union of the elements in an atmosphere of hydrogen. It is described as being decomposable by dilute hydrochloric acid with the evolution of hydrogen telluride.

When sodium telluride comes in contact with a solution of zinc acetate, acid with acetic acid, a heavy yellow-brown precipitate is formed. This telluride, when moist, is readily oxidized by the oxygen of the air with the separation of tellurium, as indicated by rapid darkening of the precipitate when in contact with air. Dilute acids decompose it with the evolution of hydrogen telluride.

The dry telluride is of a brown color. It is decomposed by dilute hydrochloric acid yielding hydrogen telluride and is readily oxidized by nitric acid. Dilute sulphuric acid has no action upon it.

Its composition is represented by the formula $\text{ZnTe} \cdot \text{H}_2\text{O}$.

Data:

0.2336 gm. substance gave 0.225 gm. H_2O , 0.1391 gm. Te, and 0.0708 gm. Zn.

For $\text{ZnTe} \cdot \text{H}_2\text{O}$	Found	Calculated
Zn	30.32%	31.00%
Te	59.48	60.47
H_2O	9.63	8.53
	99.43	100.00

¹ *These de Paris.*, (1879).

Anhydrous zinc telluride obtained by heating ZnTe . H_2O out of air contact, is of a dark dull red color. Its deportment toward reagents is entirely similar to that of the hydrated compound.

TELLURIDE OF CADMIUM

Cadmium telluride, CdTe , has been obtained by direct union of the elements in an inert atmosphere² and by the reduction of the tellurite at a red heat in hydrogen.³

When precipitated by sodium telluride in a manner entirely similar to that for the preparation of zinc telluride, CdTe appears as a heavy, maroon-colored precipitate, which is almost black when dry. This telluride is quite stable with respect to dilute acids, nitric acid alone attacking it in the cold. When moist it is readily oxidized by the air.

Data:

0.3771 gm. substance gave 0.0114 gm. H_2O , 0.1665 gm. substance gave 0.0883 gm. Te and 0.0732 gm. Cd .

For CdTe	Found	Calculated
Te	53.05%	53.02%
Cd	43.97	46.98
H_2O	3.02	00.00
	100.04	100.00

TELLURIDE OF COBALT

CoTe was prepared first by Margottet⁴ and later by Fabre,⁵ by direct union of the elements in an inert atmosphere. It is described as a grey crystalline substance of metallic lustre, quite indifferent to acids other than nitric.

When sodium telluride solution acts upon solutions of cobalt acetate acidulated with acetic acid, a heavy black precipitate is

² Margottet, *Loc. cit.*

³ Oppenheim, *J. Pr. Ch.*, 71: 226. (1857).

⁴ *Loc. cit.*

⁵ *Loc. cit.*

formed which upon analysis shows the composition $\text{Co}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$ corresponding to the telluride of sodium Na_4Te_3 . Acids other than nitric have no action upon it in the cold.

Data:

0.1637 gm. substance gave 0.1100 gm. Te, and 0.0334 gm. Co. 0.1540 gm. substance gave 0.0196 gm. H_2O .

For $\text{Co}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$

Te	67.19%	67.00%
Co	20.40	20.42
H_2O	12.72	12.58
	100.31	100.00

When heated in an atmosphere of hydrogen, $\text{Co}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$ loses water at about 200° , and at a red heat, tellurium. If the heating is continued until the weight of substance is constant, the residue consists of the normal telluride CoTe , which is entirely similar to the compound described by Margottet and by Fabre.

Data:

0.1540 gm. substance gave at constant weight, 0.1001 gm. of residue.

In $\text{Co}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$

CoTe	65.00%	65.14%
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TELLURIDE OF NICKEL

The telluride Ni_2Te_3 , melonite, is found in nature.

NiTe was prepared by Margottet and by Fabre, and is described by them as possessing properties entirely similar to those of the corresponding cobalt compound.

Sodium telluride precipitates from acetic acid solutions of nickel acetate, $\text{Ni}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$, which is not acted upon by cold hydrochloric or sulphuric acid, but is readily oxidized by nitric acid.

When heated in an atmosphere of hydrogen, $\text{Ni}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$

loses water and tellurium until the composition NiTe is attained, when it remains constant.

Data:

0.1505 gm. substance gave 0.1020 gm. Te and 0.0300 gm. Ni. 0.1595 gm. substance gave 0.0196 gm. H₂O.

For Ni₂Te₃. 4H₂O

Te	67.77%	67.07%
Ni	19.93	20.35
H ₂ O	12.28	12.58
	99.98	100.00

TELLURIDE OF LEAD

Lead and tellurium are found combined in nature as the mineral altaite.

Lead telluride is described by Margottet⁶ as a stable alloy formed by direct union of the elements in an inert atmosphere. Jay and Gilson⁷ have studied the properties of the alloys of lead and tellurium.

When sodium polytelluride solution comes in contact with a solution of lead acetate acid with acetic acid, a heavy black precipitate is formed whose composition is represented by the formula Pb₂Te₃. 4H₂O. It is not attacked by hydrochloric or sulphuric acids. Nitric acid rapidly oxidizes it.

Data:

0.1289 gm. substance gave 0.0910 gm. PbSO₄ or 0.0621 gm. Pb. and 0.0561 gm. Te. 0.2154 gm. substance gave 0.0166 gm. H₂O.

For Pb₂Te₃. 4H₂O

Te	43.74%	44.06%
Pb	48.21	47.65
H ₂ O	7.70	8.29
	99.65	100.00

⁶ *Loc. cit.*

⁷ *Am. Chem. Jour.*, **27**: 81. (1902).

When Pb_2Te_3 is heated in an atmosphere of hydrogen, it loses water, then fuses, and as the heat is increased, tellurium volatilizes leaving crystalline PbTe .

Data:

0.2156 gm. $\text{Pb}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$ gave at constant weight, 0.1694 gm. PbTe .

In $\text{Pb}_2\text{Te}_3 \cdot 4\text{H}_2\text{O}$

PbTe	78.57%	78.03%
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TELLURIDE OF SILVER

Silver telluride occurs in nature as the mineral hessite. It was synthesized first by Rose.⁸ Later Margottet prepared it by direct union of the elements, and Brauner⁹ prepared it also by direct union and by the reduction of the tellurite. Hall and Lenher¹⁰ have shown that tellurium acts upon silver salts in solution with formation of Ag_2Te .

Sodium telluride solution precipitates Ag_2Te from silver acetate solution in the presence of acetic acid, as a dark brown or black flocculent precipitate. It is perfectly stable in the air, even in the moist condition and is not acted upon by cold acids other than nitric.

Data:

0.1072 gm. substance gave 0.0880 gm. AgCl or 0.0662 gm. Ag , and 0.0386 gm. Te .

For Ag_2Te	Found	Calculated
Te	36.04%	37.13%
Ag	61.78%	62.87
H_2O	By difference	

TELLURIDES OF COPPER

Copper and tellurium occur in nature combined as the mineral rickardite, Cu_4Te_3 .

⁸ *Pogg. An.*, **18**: 64. (1830).

⁹ *J. Chem. Soc.*, **55**: 398. (1889).

¹⁰ *J. A. C. S.*, **24**: 918. (1902).

Copper telluride, Cu_2Te , was prepared by Margottet by direct union and further studied by Fabre. Parkman¹¹ has shown that when elementary tellurium remains for some time in contact with solutions of copper salts, the tellurides CuTe and Cu_2Te_3 are formed according to the conditions of the experiment.

When sodium telluride reacts with copper acetate solution in the presence of acetic acid, the normal telluride, CuTe , is formed as a heavy black precipitate. This substance is stable in the air either moist or dry, and is not decomposed by dilute acids other than nitric. Hot concentrated hydrochloric acid decomposes it slowly in the presence of the air, with the formation of cupric chloride and tellurium.

The analysis of the tellurides of copper at first presented great difficulties due to the tendency that both show of precipitating together.

The author has found that acid solutions of potassium dichromate oxidize elementary tellurium to telluric acid, from which solution hydrogen sulphide precipitates but a trace of tellurium. The copper telluride was boiled with an acid potassium dichromate solution until completely dissolved, the solution cooled, and saturated with hydrogen sulphide. The precipitated copper sulphide was digested with dilute nitric acid and the copper precipitated electrolytically, a very low current density¹² being employed to keep the trace of tellurium present from being deposited with the copper.

Data:

(1.) 0.1644 gm. substance gave 0.0548 gm. Cu.

(2.) 0.1092 gm. substance gave 0.0365 gm. Cu.

For CuTe	Found	Calculated
Cu	(1) 33.33 (2) 33.42%	33.26%
Te		66.74
		100.00

¹¹ *Am. Jour. Sci.*, [2], 33: 328. (1862).

¹² E. F. Smith's *Electro Analysis*, (4th Ed.), 199.

When copper acetate solutions are brought in contact with sodium polytelluride, anhydrous Cu_2Te_3 is formed.

Data:

0.1731 gm. substance gave 0.0411 gm. Cu.

For Cu_2Te_3	Found	Calculated
Cu	23.74%	24.90%
Te		75.10
		100.00

MERCURIC TELLURIDE

This substance occurs in nature as the mineral triemanite. Klaproth¹³ in his first study of tellurium noted the ease with which it combined with mercury, and Margottet¹⁴ mentions the preparation of mercuric telluride. The combination of the two elements is described as being very indefinite, mercury being readily distilled away from the tellurium by heat in an inert atmosphere.

Sodium telluride solution precipitates from mercuric chloride solution, a grey substance which changes first to a yellow and then to a red color, and finally to a homogeneous light brown. This final product is mercurous chloride, and tellurium is found to be dissolved in the solution. Mercuric telluride is probably formed at first, but subsequently reacts with the excess of mercuric chloride reducing it to mercurous chloride with the formation of tellurium chloride.

TELLURIDE OF BISMUTH

Bismuth telluride occurs in nature as the mineral tetradyomite. When the two elements are heated together they form various alloys which have been studied by Guthier.¹⁵

Hydrated telluride is formed when sodium telluride reacts

¹³ *An. Ch.*, **25**: 276. (1798).

¹⁴ *Loc. cit.*

¹⁵ *Zeit. Anorg. Chem.*, **31**: 331. (1902).

with a solution of bismuth acetate. This telluride is unaffected by hydrochloric acid or sulphuric acid in the cold, but is decomposed by both when heated in the presence of the air. Nitric acid readily oxidizes it. When heated in hydrogen, the water is first expelled, then the telluride fuses and loses both tellurium and bismuth.

TELLURIDE OF MANGANESE

When sodium telluride acts upon manganous acetate in the presence of acetic acid, a light brown precipitate is first formed which rapidly changes to a dark green. If the acetic acid be in excess or the solution hot, the telluride is decomposed with the formation of hydrogen telluride which itself decomposes and deposits tellurium upon the walls of the vessel above the solution. The dark green precipitate is immediately blackened by exposure to air and dilute acids decompose it very readily with liberation of H_2Te .

TELLURIDE OF ARSENIC

The tellurides AsTe^{16} , $\text{As}_2\text{Te}_3^{17}$ and $\text{As}_8\text{Te}_3^{17}$ have been prepared by direct union of the elements.

Sodium telluride precipitates from aqueous solution of arsenious oxide a telluride of arsenic contaminated with tellurium. This substance is brown in color.

Arsenic telluride was allowed to stand for several hours in contact with a strong solution of sodium polytelluride. The solution after filtration was dark brown in color and careful examination revealed the presence of both arsenic and tellurium in the solution. This would seem to indicate the existence of telluro compounds analogous to the sulpho salts.

TELLURIDE OF GOLD

Telluride of gold was prepared first by Berzelius and then by Brauner¹⁸ by direct union in proper proportions.

¹⁶ Oppenheim, *J. Pra. Ch.*, **71**: 278. (1857).

¹⁷ Szarvassi and Massinger, *Ber.*, **30**: 1343. (1897).

¹⁸ *J. Chem. Soc.*, **55**: 389. (1889).

The naturally occurring tellurides of gold are sylvanite, calaverite, krennerite and petzite. According to Lenher,¹⁹ these substances can scarcely be regarded as true chemical compounds, for he has found that these substances react with gold solutions precipitating gold in a manner entirely similar to that of elementary tellurium.²⁰ The alloys or tellurides formed by direct union act similarly.

It has been found by the author that sodium telluride precipitates gold and tellurium from solutions of sodium sulphaurate, but the substances formed do not appear to be of constant composition.

When sodium telluride reacts with an excess of neutral auric chloride solution, a precipitate of metallic gold is formed which contains no tellurium. This may be due to one of two reactions, viz.: a telluride of gold may be formed which at once reacts with the excess of auric chloride reducing it in a manner similar to the action of the natural tellurides; or the sodium telluride may act simply as a reducing agent toward the auric chloride according to the equation $2 \text{AuCl}_3 + \text{Na}_2\text{Te} = 2 \text{NaCl} + \text{TeCl}_4 + 2 \text{Au}$.

TELLURIDE OF PLATINUM.

According to Rössler,²¹ equivalent proportions of platinum and tellurium unite explosively at elevated temperatures forming PtTe_2 . When this substance is fused, PtTe may be crystallized from it. It has been shown by Fischer²² that elementary tellurium acts as a reducing agent toward platinum solutions.

Sodium telluride solution, acting upon a solution containing platinum tetrachloride in excess, produces a heavy black precipitate, which is composed entirely of platinum. The tellurium is found in the solution. The reaction may be expressed by the equation, $2 \text{Na}_2\text{Te} + 3 \text{PtCl}_4 = 4 \text{NaCl} + 2 \text{TeCl}_4 + 3 \text{Pt}$.

¹⁹ *J. A. C. S.*, **24**: 355. (1902).

²⁰ Hall and Lenher, *J. C. S.*, **24**: 918. (1902).

²¹ *Zeit. Anorg. Chem.*, **15**: 405. (1897).

²² *Pogg. An.*, **12**: 502. (1828).

TELLURIDE OF IRON

Ferrous telluride was prepared by Margottet²³ and also by Fabre,²⁴ by the direct union of the elements in an inert atmosphere.

When sodium telluride acts upon a solution of ferric chloride acid with acetic acid, a black precipitate is formed which is composed entirely of tellurium. The iron is reduced to the ferrous condition and the solution contains a large amount of tellurium as the tetrachloride. This is in accord with the fact established by Lenher²⁵ that tellurium is soluble in ferric chloride forming ferrous chloride and tellurium tetrachloride.

TELLURIDE OF PALLADIUM

Fischer²⁶ has shown that tellurium acts as a reducing agent toward palladium solutions in a manner analogous to its action upon silver, gold and platinum solutions.

Sodium telluride precipitates from sodium palladous chloride solution a very finely divided black precipitate of palladous telluride. This substance is not acted upon by hydrochloric or sulphuric acids in the cold, but is oxidized by nitric acid and very readily dissolved by *aqua regia*.

When sodium telluride reacts with ammonium molybdate or sodium tungstate, dark, strongly colored solutions are formed which are quite stable in the air. With these solutions hydrochloric acid yields black flocculent precipitates which contain tellurium and either molybdenum or tungsten as the case may be. Here we have further evidence of the existence of telluro salts.

²³ *Loc. cit.*

²⁴ *Loc. cit.*

²⁵ *J. A. C. S.*, **30**: 744. (1908).

²⁶ *Pogg. An.*, **12**: 502. (1828).

SUMMARY

1. Sodium telluride, Na_2Te , is a colorless crystalline salt and is highly hydrated.

2. Tellurium dissolves in sodium telluride solution with the formation of Na_4Te_3 . Beyond the proportions represented by Na_4Te_3 , tellurium is not soluble in sodium telluride. Na_4Te_3 does not crystallize as such, but breaks down upon evaporation into Na_2Te and tellurium.

3. Potassium telluride, K_2Te , does not crystallize from aqueous solution, but is precipitated from strong solution by alcohol.

4. Telluride of zinc is yellow when freshly precipitated and brown when dry. Its composition is $\text{ZnTe} \cdot \text{H}_2\text{O}$. The anhydrous telluride is dark red in color.

5. Cadmium telluride, CdTe , is precipitated as a maroon colored substance, almost black when dry.

6. Nickel forms a telluride of the composition $\text{Ni}_2\text{Te}_3 \cdot 4 \text{H}_2\text{O}$, black. When heated in hydrogen it yields NiTe .

7. Cobalt forms a telluride of analogous composition and similar properties to that of nickel.

8. Lead forms the telluride $\text{Pb}_2\text{Te}_3 \cdot 4 \text{H}_2\text{O}$ which is decomposed by heat into PbTe , water and tellurium.

9. Ag_2Te is precipitated by sodium telluride from silver acetate solutions.

10. Copper forms the two tellurides CuTe and Cu_2Te_3 by precipitation with Na_2Te and Na_4Te_3 respectively.

11. A telluride of arsenic is formed by precipitation, and is soluble in excess of Na_4Te_3 solution. This indicates the existence of a telluro salt of arsenic analogous to the sulpho salts.

12. Mercuric telluride is precipitated from mercuric chloride solution, but reacts rapidly with excess of mercuric chloride forming mercurous chloride and tellurium chloride.

13. Sodium telluride precipitates gold from auric chloride solution and platinum from platinic chloride solution, the tellurium dissolving as the tetrachloride.

14. By the action of sodium telluride upon ammonium molybdate and upon sodium tungstate we have indications of the existence of telluro salts.

The author desires in closing to make grateful acknowledgment to Professor Victor Lenher, under whose guidance and inspiration this work has been carried out.

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A STUDY OF THE METALLIC TELLURITES

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A STUDY OF THE METALLIC TELLURITES

HISTORICAL

Berzelius was the first to make a study of the tellurites. His first presentation of the subject was in the form of a paper which he read before the Royal Swedish Aeademy of Science in 1832. This paper, however, was not published in the reports of the society for that year, because of a lack of space. Instead, there appeared in Berzelius' *Jahresbericht* for 1833,¹ a brief article describing tellurous acid, and containing a few general statements regarding its salts.² In the following year the reports of the Swedish Aeademy³ contained an article by Berzelius which dealt in a systematic way with tellurium, the tellurides, tellurates, tellurites, and some salts of tellurium in which this element played the part of a base. On account of the scope of this paper it necessarily had to treat any particular part of the subject very briefly.

In this article, Berzelius notes that tellurium dioxide is a very weak acid, and that it is quite easily displaced from its salts by carbon dioxide of the air. The alkaline tellurites are soluble, the alkaline earth tellurites are slightly soluble, while the rest are insoluble as a rule. Furthermore, he finds that tellurous acid forms salts of different degrees of saturation, corresponding to the normal, di- and quadri- or tetratellurites. All of these are quite easily fusible, particularly the di- and tetratellurites, and the latter after being fused form clear colorless glasses.

¹ 13: 96.

² See also *Pogg.*, 28: 396, -1833.

³ *Kongliga Svenska Vetenskaps Akademiens Handlingar*, 1833, p. 277; *Pogg.*, 32: 1-577, -1834, and *Ann. de Ch. et de Phys.* (2) 58: 225, -1835.

Berzelius prepared the alkaline tellurites by fusing together tellurium dioxide and sodium or potassium carbonate. When the carbonate was used in excess, the tellurium dioxide displaced carbon dioxide, molecule for molecule, forming a normal tellurite. He gives fairly detailed accounts of the alkaline and alkaline earth tellurites, but in the case of the tellurites of the other metals he practically confines himself to a brief description of the precipitates which are formed when solutions of the metallic salts are treated with a solution of an alkaline tellurite. Very few analyses are published in this paper.

In his *Lehrbuch der Chemie* (1847), Berzelius devotes only a very little space to the discussion of the tellurites, and gives no new information.

In 1857, Oppenheim⁴ described a precipitate which he obtained by adding to a cadmium solution, a solution of sodium tellurite. He published no analysis.

In 1885, Klein and Morel⁵ stated that, while trying to prepare the double oxalate of potassium and tellurium by treating potassium tellurite with oxalic acid, they obtained a white amorphous powder whose composition approximated $K_2O, 6TeO_2, 2H_2O$.

In 1890, Dana and Wells⁶ published a description and an analysis of a mineral which had been found in Honduras, and which appeared to be a ferric tellurite. They called this mineral Durdenite. To this article is appended a note by Hillebrand on the mineral Emmonsite, which is another ferric tellurite.

In an article published by Whitehead⁷ in 1895 we find the statement that when ammonium chloride is added to a solution of sodium tellurite, tellurium dioxide is precipitated.

⁴ *Jr. Prak. Chem.*, **71**: 266, -1857.

⁵ *Compt. Rend.*, **100**: 1140, -1885.

⁶ *Am. Jr. Sc.*, (3) **40**: 78, -1890.

⁷ *Jr. Am. Chem. Soc.*, **17**: 849, -1895

INTRODUCTION

In the work described in the following pages, the tellurites of the following were studied: potassium, sodium, silver, barium, magnesium, cadmium, nickel, cobalt, manganese, lead, and ammonium. In addition to the normal tellurites, the di- and tetratellurites of the alkali metals were also studied. The normal and ditellurites of potassium and sodium were prepared by fusing tellurium dioxide with the theoretical quantities of the alkali carbonates. The tetratellurites of potassium and sodium were obtained by the decomposition of the corresponding ditellurites with water. The tellurites of the other metals were prepared by precipitation from solutions of their salts (usually the chlorides) by means of sodium tellurite.

The tellurium dioxide used in this work was prepared in the following manner. Ordinary commercial tellurium was dissolved in aqua regia, and the solution evaporated to dryness. After heating to expel all of the nitric acid, the residue was redissolved in hydrochloric acid and treated with a saturated solution of sodium bisulphite. The impure tellurium thus obtained was fused with an excess of potassium cyanide. The fused mass was pulverized and extracted with boiling water. The tellurium together with selenium and sulphur which might have been present, were dissolved in the form of potassium telluride and potassium seleno- and sulphocyanates, and passed through the filter. The residue invariably remaining on the filter was again fused with potassium cyanide and treated as before.

Air was then bubbled through the solution. The potassium telluride was oxidized, liberating tellurium, while the seleno- and sulpho-cyanates were unaffected. In this way the tellurium was separated from selenium and sulphur. The precipitated tellurium, after filtering and washing, was dissolved in dilute nitric acid and recrystallized from this solution as the basic nitrate. Finally this nitrate was heated strongly in a platinum crucible, and tellurium dioxide obtained. The dioxide was then fused, to insure complete removal of oxides of nitrogen. The product was perfectly white.

METHODS OF ANALYSIS

In the analysis of the tellurites studied, the following methods were used. Water was usually determined by loss of weight on heating. In some cases a temperature of 450° was necessary for the complete dehydration of the substance, but in such cases it was not necessary to continue the heating for more than fifteen minutes. In the case of the alkaline tellurites, on account of the oxidation of these salts on heating in the air, it was also deemed advisable to weigh the water directly, after first absorbing in sulphuric acid. This will be further discussed later.

The tellurium and basic element were then separated by one of the following general methods. (1) Volatilization of the tellurium in a stream of hydrochloric acid gas. This method was devised by Lenher and afterward used by Hutchins⁸ in the analysis of a number of tellurates. (2) Precipitation of the tellurium in presence of the other metal, by means of sulphur dioxide and hydrazine hydrochloride,⁹ and the subsequent determination of the base in the filtrate by one of the usual methods.

The first of these methods is not applicable to the tellurites of those metals whose chlorides are appreciably volatile below 500° . It was used in the analysis of the potassium, sodium, silver and lead salts. A weighed amount of the substance to be analyzed was placed in a porcelain boat and heated in a combustion tube in a current of hydrochloric acid gas. That part of the tube which contained the boat, was surrounded by a sheet iron jacket, leaving an air space of about one inch between the jacket and the glass tube. The object of this arrangement was to make the heating more uniform. The tellurium was volatilized as TeO_2 , 2HCl . The greater portion of the tellurium was condensed in the cooler part of the tube. The excess of the hydrochloric acid, together with a little tellurium was absorbed

⁸ *Jr. Am. Chem. Soc.*, **27**: 1157, -1905.

⁹ Lenher and Homberger, *Jr. Am. Chem. Soc.*, **30**: 387, -1908.

in a Drechsel wash bottle containing water. In the earlier experiments, two wash bottles in series were used, but later it was found that one is all that is necessary for most experiments.

The chloride remaining in the boat was weighed and calculated as metal. The tellurium sublimate in the glass tube was washed into a beaker, and the solution from the wash bottle was added. After concentrating this solution, the tellurium was precipitated by means of sulphur dioxide and hydrazine hydrochloride, and determined according to the method of Lenher and Homberger.

POTASSIUM TELLURITE

The normal salt was prepared by fusing in a platinum crucible a mixture of equimolecular quantities of potassium carbonate and tellurium dioxide. The mixture fused quite readily, giving off carbon dioxide. In order to prevent oxidation to tellurate, the air in the crucible was displaced by a stream of carbon dioxide from a generator. On cooling, a white crystalline mass was obtained, which was deliquescent, and extremely soluble in water. The aqueous solution slowly deposited tellurous acid, on exposure to air, and more readily when air was bubbled through the solution. On heating, however, the precipitate again dissolved, showing that at higher temperatures tellurous acid will displace carbonic acid.

A small amount of a strong solution of this substance was allowed to evaporate in a dessicator over sulphuric acid. Another vessel containing solid caustic potash was placed within the dessicator to absorb the carbon dioxide of the air. The solution did not crystallize but on evaporation it gradually formed a thick syrup which finally solidified. The product was a hard, transparent and homogeneous mass, having a waxy or resinous appearance without the slightest external indication of crystallization.

Two successive portions of this material were obtained, as it solidified from solution, and were analyzed, with the following results.

	Found.		Calculated for $K_2TeO_3 \cdot 3H_2O$.
	I.	II.	
K %	25.25	25.82	25.43
Te %	40.62	40.83	41.44
H ₂ O%	17.71	17.09	17.54

These results indicate that although potassium tellurite, when prepared as described, cannot be crystallized from an aqueous solution, it is nevertheless a definite compound, $K_2TeO_3 \cdot 3H_2O$. This compound was also prepared by treating tellurium dioxide with a solution of caustic potash, either cold or hot. The combination seems to take place only in the proportion of $2KOH : TeO_2$, so that if we have more than this proportion of tellurium dioxide, some will remain undissolved. Tellurium dioxide dissolves in a hot solution of potassium carbonate, although not so readily as in caustic potash.

POTASSIUM DITELLURITE

Potassium ditellurite was prepared by fusing together one gram molecule of potassium carbonate and two gram molecules of tellurium dioxide. It fuses more readily than the normal salt, and on cooling appears as a white crystalline mass.

Potassium ditellurite is insoluble in cold water. It dissolves in boiling water, but on cooling, the solution decomposes, yielding the normal tellurite, which remains in solution, and the tetratellurite which is precipitated. The ditellurite decomposes slightly even at the boiling temperature, for complete solution of the substance was never obtained.

POTASSIUM TETRATELLURITE

Berzelius obtained the tetratellurite of potassium by boiling a solution of potassium carbonate with tellurium dioxide, filtering the boiling solution and allowing to cool slowly. The tetra-

tellurite separated out in the form of small grains attached to the walls of the vessel. During the present work the tetratellurite was prepared by the decomposition of the ditellurite with water. Finely pulverized ditellurite was boiled with water for a short time. The hot solution was quickly filtered. White shining flakes separated out as the solution cooled. This compound was analyzed, and its composition found to conform to the formula $K_2Te_4O_9 \cdot 4H_2O$.

	Found.		Calculated for $K_2Te_4O_9 \cdot 4H_2O$.
	I	II	
K %	9.76	10.00	9.73
Te %	64.51	64.20	63.41
H ₂ O %	8.61	8.35	8.95

This salt when boiled with its mother liquor dissolves, but separates again on cooling. Prolonged treatment with boiling water decomposes it, leaving tellurium dioxide as the final product. A quantity of the salt which had been washed repeatedly on the filter with boiling water left a white powder which contained 0.66% water, 0.47% potassium, and 78.52% tellurium. It was therefore nearly 99.0% tellurium dioxide. It is probable that the carbon dioxide of the air played a part in this decomposition. This question, however, has not yet been thoroughly investigated.

SODIUM TELLURITES

Normal sodium tellurite was prepared in a manner similar to that in which the corresponding potassium salt was obtained. And, as might be expected, the properties of these two salts are similar. Sodium tellurite is readily soluble in water. It is not deliquescent, and can be crystallized from solution in the form of broad, flat plates of hexagonal outline. It was also obtained in slender needles, grouped in radiating clusters. The evaporation of the solution was conducted in the same manner as with

the potassium salt, namely, in a dessicator over sulphuric acid and in the presence of solid caustic potash.

Unlike potassium tellurite which contains three molecules of water, sodium tellurite contains five molecules of water of crystallization, $\text{Na}_2\text{TeO}_3 \cdot 5\text{H}_2\text{O}$.

	Found.		Calculated for $\text{Na}_2\text{TeO}_3 \cdot 5\text{H}_2\text{O}$.
	I	II.	
Na %.....	14.72	14.77	14.79
Te %.....	40.33	40.49	40.94
H_2O %.....	28.89	29.14	28.88

An interesting, though not unusual, ease of equilibrium was discovered in the system, sodium tellurite, water and alcohol. If to a strong solution of sodium tellurite we add about twice its volume of 95% alcohol, the two liquids do not mix. There is, however, a redistribution of the water between the alcohol and the tellurite. The alcoholic layer increases in volume by abstracting water from the tellurite solution, while the latter becomes more concentrated. Long standing and repeated shaking will not produce any further changes in this system. If, now, we add solid sodium tellurite, it will slowly dissolve, increasing the volume of the tellurite solution, and withdrawing water from the alcoholic layer. But if we add, instead, about five volumes of absolute alcohol, the water is almost completely withdrawn from the sodium tellurite, and the latter is precipitated. Potassium tellurite and alcohol behave similarly.

The sodium di- and tetratellurites are analogous to the corresponding potassium salts, both in their methods of preparation and in their properties. Both of these compounds fuse below a red heat, and on cooling form clear glasses. The ditellurite, however, like the corresponding potassium salt, can also be obtained crystalline by fusion. The tetratellurite, when prepared by decomposing sodium ditellurite with water, has the composition $\text{Na}_2\text{Te}_4\text{O}_9 \cdot 4\text{H}_2\text{O}$.

	Found.		Calculated for $\text{Na}_2\text{Te}_4\text{O}_9 \cdot 4\text{H}_2\text{O}$.
	I	II	
Na %.....	6.06	5.78	5.97
Te %.....	65.77	66.35	66.07
H ₂ O %.....	9.64	9.43	9.32

AMMONIUM TELLURITE

Berzelius attempted to prepare ammonium tellurite by dissolving tellurous acid in ammonia, and then adding ammonium chloride or alcohol. In both instances he obtained a flocculent precipitate, which was insoluble in water, but readily dissolved in ammonia. He also obtained the same body by warming a solution of ammonium carbonate with tellurous acid or tellurium tetrachloride, and adding ammonium chloride. On heating this body, ammonia was evolved, and a residue of tellurium dioxide remained. The amount of this residue in one case was 83.1%: in another it was 83.87%, while the calculated amount of tellurium dioxide in the compound $(\text{NH}_4)_2\text{Te}_4\text{O}_9 \cdot 4\text{H}_2\text{O}$ is 83.7%. He therefore concluded that his precipitates were tetratellurites, exactly analogous in composition to the corresponding salts of potassium and sodium. Berzelius also evaporated to dryness, with the aid of gentle warming, a solution of tellurous acid in ammonia. He found the residue to be principally hydrated tellurium dioxide containing a little ammonia.

In the present work tellurium dioxide was dissolved in ammonium hydroxide (sp. gr. 0.91) by heating in sealed tubes for ten hours at a temperature of 95°–100°. After cooling and filtering the solution was allowed to evaporate spontaneously. As the solution evaporated, small crystals were obtained in the form of short needles arranged in radiating groups, or clusters of thin transparent plates. On drying these became opaque. They dissolved readily in ammonia, but were insoluble in water.

They were analyzed as follows: A weighed amount of the residue was placed in a porcelain boat inside of a glass combus-

tion tube. This tube was connected to an absorption apparatus containing a standard solution of sulphuric acid. While a slow current of dry air was drawn through the tube, the boat was heated, gently at first, increasing the temperature gradually to the full heat of the Bunsen burner. A considerable amount of moisture was condensed upon the cooler part of the tube. The residue in the boat was weighed as tellurium dioxide. The excess of acid in the absorption apparatus was then titrated with standard alkali, and the amount of ammonia estimated. The water was estimated by difference.

The following composition was found: ammonia 1.69%, tellurium dioxide 89.19%, and water 9.12%. This would correspond to the formula $\text{NH}_3 \cdot 5\text{TeO}_2 \cdot 5\text{H}_2\text{O}$ or $5\text{H}_2\text{TeO}_3 \cdot \text{NH}_3$. It is not believed that this is a definite compound. It is more likely that this is but one stage in the decomposition of ammonium tellurite to hydrated tellurium dioxide. The crystals obtained from the ammoniacal solution were probably a definite ammonium tellurite. This compound, however, is so unstable that it can exist only in solution, or when surrounded by the mother liquor, and when dried it spontaneously decomposes even at the ordinary temperature.

MAGNESIUM TELLURITE

This substance was obtained from a solution of magnesium chloride by adding a solution of sodium tellurite. It is a white flocculent precipitate, which is slightly soluble in water. On standing for a time in the mother liquor or in water, it becomes granular and heavy. The composition of the precipitate is not affected by varying the proportion of the two salts from which it is formed.

In analyzing this salt, after determining the water by loss in weight on heating, it was dissolved in hydrochloric acid, and the tellurium precipitated in the usual manner by means of sulphur dioxide and hydrazine hydrochloride. The remaining solution was then evaporated to dryness, the residue taken up in water, and the magnesium precipitated as magnesium am-

monium phosphate, which was ignited and weighed as pyrophosphate.

This tellurite was found to have the composition, $5\text{MgTeO}_3 \cdot 9\text{H}_2\text{O}$.

	H ₂ O	Te	Mg
Calculated for..... 5MgTeO ₃ ·9H ₂ O.	13.94	54.91	10.84
Found I.....	13.48	55.29	9.98
“ II.....	13.62	54.91	.....
“ III.....	13.65	55.39	9.91
“ IV.....	14.29	55.10	9.70
“ V.....	13.36	55.59	9.93

In the above table, numbers I, II, and III were precipitated from solutions containing excess of sodium tellurite, while IV and V were precipitated from solutions containing an excess of magnesium chloride.

Owing to the somewhat unusual ratio of the water to magnesium tellurite in this compound, a more careful study was made of this relation. A quantity of the dried precipitate, equivalent to one gram of anhydrous tellurite, was heated at various temperatures until the weight became constant. Then, from the total water content and the loss in weight at each temperature, it was possible to calculate the amount of water still retained. The following table shows the results which were obtained.

Temp.	H ₂ O held by 1 gm. MgTeO ₃ .	Temp.	H ₂ O held by 1 gm. MgTeO ₃ .
20°.....	0.1545	260°	0.0758
100°.....	0.1360	300°	0.0250
130°.....	0.1170	330°	0.0130
175°.....	0.0965	360°	0.0080
200°.....	0.0860	400°	0.0050
220°.....	0.0838	450°	None

These results are also shown by the curve, Fig. 1. It will be seen that at about 260° there is a sharp break in the curve, and that the amount of water retained at this temperature is very nearly one half of the original amount, 0.1545 gm. Above this temperature there is a rapid falling off in the water content, until at 450° all of the water can be driven off in fifteen minutes.

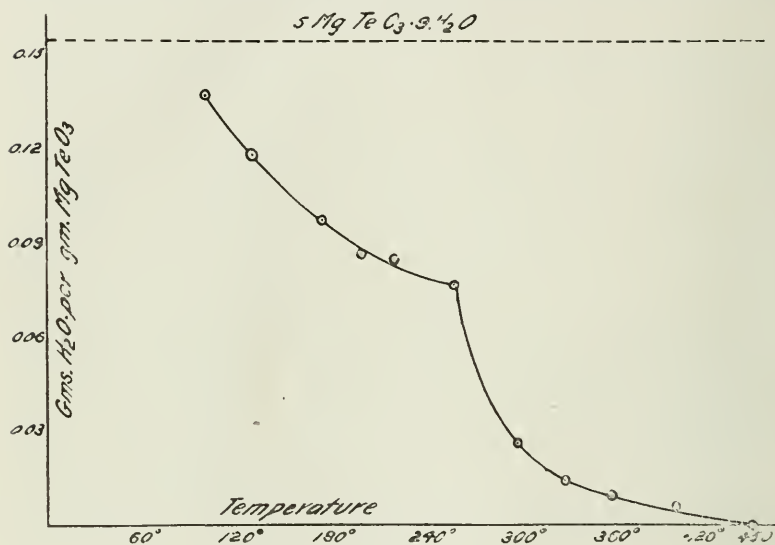


FIG. 1.

This experiment shows that between 450° and ordinary temperatures, there exist at least two definite hydrates of magnesium tellurite, namely, $5\text{MgTeO}_3 \cdot 9\text{H}_2\text{O}$, and $10\text{MgTeO}_3 \cdot 9\text{H}_2\text{O}$. It might also be noted that the composition at 100° , as calculated from the above results, is $2\text{MgTeO}_3 \cdot 3\text{H}_2\text{O}$, although this may have no special significance, since no data were obtained for temperatures below 100° . It is also quite evident that most of the water in this compound is quite firmly held.

BARIUM TELLURITE

To obtain this substance, a solution of sodium tellurite was added to a solution of barium chloride. A white flocculent precipitate was obtained, which was only slightly soluble in water.

Attempts were made to obtain barium tellurite in crystalline form but these were unsuccessful. Analysis of different samples showed a considerable variation in composition. Investigation showed that the precipitates always contained barium chloride, and sometimes in considerable quantities. This barium chloride could not be washed out completely by repeated and long continued boiling with large quantities of water. Accordingly the precipitation was performed in dilute solutions, containing exactly equivalent quantities of the two salts. Under these conditions the precipitates always contained small amounts of barium chloride which could not be washed out.

The analysis of this substance was carried out in the following way. Water was determined in the usual way. The chlorine was determined by precipitation with silver nitrate, from a nitric acid solution of the barium tellurite. After removing the excess of silver nitrate by adding hydrochloric acid, the barium was precipitated by means of ammonium sulphate. The filtrate from the barium sulphate was evaporated to dryness, and the residue treated repeatedly with hydrochloric acid to remove all of the nitric acid. Finally from this hydrochloric acid solution the tellurium was precipitated by sulphur dioxide and hydrazine hydrochloride. The method of volatilization in hydrochloric acid gas could not be used in this case, since all of the tellurium could not be driven off without raising the temperature so high that barium chloride would volatilize.

The proportion of barium to tellurium was greater than the normal salt should have. But in all cases the precipitates also contained chlorine in appreciable quantities. If the chlorine contained be calculated as barium chloride, and the tellurium as normal barium tellurite, the results agree with the analysis obtained. This is particularly evident in those samples which were precipitated in presence of excess of barium chloride.

Several samples were analyzed, in all of which the proportions of barium chloride, tellurite and water varied considerably. The following analyses are typical examples. The first sample was precipitated in presence of excess of barium chloride: the second one from equivalent quantities of this salt and sodium tellurite.

I.

	Found.	Calculated for $8\text{BaTeO}_8 \cdot 5\text{BaCl}_2 \cdot 4\text{H}_2\text{O}$
H_2O %.....	1.90	1.99
Cl %.....	9.43	9.82
Ba %.....	48.68	49.50
Te %.....	29.23	28.29

II.

	Found.	Calculated for $20\text{BaTeO}_8 \cdot \frac{1}{2}\text{BaCl}_2 \cdot 20\text{H}_2\text{O}$
H_2O %.....	5.07	5.35
Cl %.....	0.53	0.53
Ba %.....	41.83	41.89
Te %.....	38.33	37.95

CADMIUM TELLURITE

This salt was obtained as a white amorphous, insoluble precipitate, by the interaction of cadmium chloride and sodium tellurite.

In its analysis the method of volatilization could not be used for the separation of the tellurium, on account of the volatility of cadmium chloride. The tellurium was therefore first precipitated from a hydrochloric acid solution of the material by means of sulphur dioxide and hydrazine hydrochloride. In the filtrate from the tellurium, the cadmium was determined in one of two ways. (1) The solution was evaporated to dryness, the residue taken up in water, and the cadmium precipitated as carbonate by means of potassium carbonate, and weighed as oxide. (2) The solution was first neutralized with potassium hydroxide, and potassium cyanide was added until the precipitate first formed just redissolved. This solution was then electrolyzed, using a current density of 0.5 to 0.8 amperes per 100 square

centimeters, with about 4 to 4.5 volts. After five hours the voltage was increased to 5 volts for an hour.

The composition found did not agree with the normal tellurite. The tellurium was always slightly high and the cadmium correspondingly low. The following gives the average composition found, together with the calculated results for $3\text{CdTeO}_3 \cdot 2\text{H}_2\text{O}$.

	Found.	Calculated for $3\text{CdTeO}_3 \cdot 2\text{H}_2\text{O}$.
Cd %.....	36.09	37.47
Te %.....	44.20	42.53
H_2O %.....	3.67	4.00

These results are explained by the fact that when tellurium is precipitated in the presence of cadmium, it carries some of the cadmium down with it. This is made quite evident from the following experiments.

I. Some tellurium which had been thus precipitated in the presence of cadmium, was dissolved in a little aqua regia, and the solution evaporated to dryness. The residue was then taken up in dilute hydrochloric acid and precipitated by means of hydrogen sulphide. This precipitate was digested for several hours in a warm place with yellow ammonium sulphide. The residue left by the ammonium sulphide was treated with hot concentrated hydrochloric acid, and filtered. After nearly neutralizing the filtrate with caustic potash, it was treated with hydrogen sulphide. A small amount of cadmium sulphide was obtained.

II. A weighed amount of pure tellurium dioxide was mixed with cadmium chloride (about 0.8 gm.). After dissolving in hydrochloric acid, the tellurium was precipitated with sulphur dioxide and hydrazine hydrochloride. The following results were obtained.

	Te found.	Te calculated.
I.....	0.7037	0.6929
II.....	0.9476	0.8754

It will be observed that the weight of the tellurium which was precipitated was in each case considerably greater than the calculated amount.

III. A determination of tellurium by means of sulphur dioxide and hydrazine hydrochloride was made in a weighed amount of pure tellurium dioxide. The tellurium thus obtained was again dissolved and the determination repeated. The results were as follows:

	Te found	Te used
I.....	0.4045	0.4052
II.....	0.4034	0.4045

IV. Exactly equivalent quantities of cadmium chloride and sodium tellurite, both in solution, were brought together, and the resulting precipitate was filtered off. The clear filtrate was then evaporated to small bulk and treated with hydrogen sulphide. No precipitate was formed, showing that both cadmium and tellurium had been completely removed in the first precipitate. This precipitate, therefore, could have been nothing other than the normal tellurite.

SILVER TELLURITE

When a solution of sodium tellurite is added to a solution of silver nitrate, a pale lemon yellow, flocculent precipitate is formed. This precipitate remains pale yellow as long as the silver nitrate is in excess, but when sodium tellurite is added in excess the color of the precipitate quickly changes to white. On

drying, both precipitates assume a buff color, and are almost indistinguishable from each other. On standing, however, the one which was precipitated in presence of an excess of silver nitrate begins to turn dark in color, and in the course of a week or two has changed completely to a dark bluish gray color. The other does not change, and has actually been kept for twenty months without undergoing any modification.

Nevertheless both of these precipitates have the same composition, and when dried, both are anhydrous. The methods of analysis here used were the same as in the case of the alkaline tellurites. In the following table I and II were precipitated in presence of an excess of silver nitrate, while in III and IV the proportion was reversed.

	Ag	Te
Calculated for..... Ag ₂ TeO ₄ .	55.14	32.59
Found I.....	55.09	32.96
" II.....	54.90	32.51
" III.....	54.89	32.52
" IV.....	55.25	32.52

Silver tellurite can exist in still other forms. When heated to a temperature of 250°, it becomes deep blue or purple in color. This change takes place without any change in weight. On heating still higher, to 450° or 500°, it again changes to a pale yellow. In this last condition it can be cooled down to ordinary temperatures unchanged, provided it is not disturbed during the cooling. But if during this cooling, and while it is still quite hot, it is disturbed by compression with a glass rod, the mass immediately changes to the purple variety.

Again, when freshly precipitated silver tellurite is treated with ammonium hydroxide it dissolves immediately, and when this solution is allowed to evaporate spontaneously it will deposit brownish yellow crystals. As no other residue remains from the ammoniacal solution, these crystals must contain all of the original silver tellurite. They contain neither ammonia nor water, and can be heated to 500° or higher without any change

in weight. On cooling, after being thus heated, these crystals again yield the ordinary, pale yellow silver tellurite.

It thus appears that silver tellurite can exist in a number of different varieties. The freshly precipitated salt is soluble in acetic and tartaric acids, also in nitric and sulphuric acids. Hydrochloric acid decomposes it with the formation of silver chloride and tellurium tetrachloride. It is insoluble in water.

An attempt was made to obtain silver telluride in crystalline form in the same way in which Hutchins crystallized some of the precipitated tellurates.¹⁰ This method was to allow the precipitate to stand in contact with water containing minute quantities of free acids. This method, however, proved unsuccessful with the tellurites. It might be stated that the precipitated tellurites as a rule show very little or no tendency to pass into the crystalline state.

NICKEL TELLURITE

This compound was obtained from a solution of nickel chloride and a solution of sodium tellurite, as a pale, greenish-yellow precipitate. This precipitate is light and amorphous.

In the analysis, after removal of tellurium by precipitation, the nickel was determined by precipitating from a chloride solution by means of potassium carbonate, and then igniting the nickel carbonate to oxide. In this form the nickel was weighed.

The composition of nickel tellurite was found to be $\text{NiTeO}_3 \cdot 2\text{H}_2\text{O}$.

	Found.	Calculated for $\text{NiTeO}_3 \cdot 2\text{H}_2\text{O}$.
Ni %.....	21.40	21.72
Te %.....	47.96	47.21
$\text{H}_2\text{O}\%$	13.62	13.32

When heated, the light yellow-green tellurite loses water and turns to a light brown color.

¹⁰ *Jr. Am. Chem. Soc.*, **27**: 1157, -1905.

COBALT TELLURITE

This salt was obtained in the wet way from a solution of cobalt chloride, in the form of a dark, purplish-blue precipitate. When heated to 300° – 400° it melts without change of color, and loses water at the same time. The method of analysis was the same as that of the nickel salt. The ignition of the cobalt carbonate, however, was performed in an atmosphere of carbon dioxide to prevent oxidation. The formula of cobalt tellurite is $\text{CoTeO}_3 \cdot \text{H}_2\text{O}$.

	Found.	Calculated for $\text{CoTeO}_3 \cdot \text{H}_2\text{O}$.
Co %.....	23.39	23.36
Te %.....	50.30	50.52
H ₂ O %.....	7.79	7.12

MANGANESE TELLURITE

This is a very unstable compound. When a solution of manganous chloride is added to a solution of sodium tellurite, there is formed a voluminous white precipitate, which is faintly pink or flesh-colored. On standing, this gradually changes to a deep chocolate-brown color. The change takes place more rapidly when it is brought into direct contact with air. This change is due to oxidation of the manganese to the trivalent state. When the chocolate colored substance is treated with hydrochloric acid, a dark, greenish-brown solution of manganic chloride is formed. This color is discharged by diluting the solution with water, or by boiling; in the latter case chlorine is evolved.

If the precipitation is carried out with solutions which had been previously thoroughly boiled to expel the air, the precipitate is perfectly white, and remains so as long as contact with air is avoided.

The extent of oxidation was determined by boiling the material with hydrochloric acid, distilling the chlorine into a solution of potassium iodide, and titrating the iodine with sodium thiosulphate. The tellurium was precipitated from the hydrochloric acid solution by sulphur dioxide and hydrazine hydrochloride. Finally the manganese in the filtrate from the tellurium was precipitated as manganese ammonium phosphate, ignited to pyrophosphate, and weighed. The water was estimated by difference.

The atomic ratio of manganese to tellurium was found to be 1:1, so that the precipitate first formed was undoubtedly normal manganous tellurite. The ratio of active oxygen to manganese, however, was less than would be required for complete oxidation of the manganese to the trivalent condition, and this ratio also varied in different samples. One sample of the freshly prepared precipitate was washed by decantation, and suspended in water, while air was bubbled through the mixture for a week. It then showed 0.0043 gm. of active oxygen, 0.1026 gm. manganese, and 0.2517 gm. tellurium. Hence only about 28% of the manganese was oxidized.

The freshly precipitated manganese tellurite seems to be more sensitive toward oxygen than after it has stood for some time. White manganese tellurite was prepared by bringing together under a layer of melted paraffine a solution of manganese chloride and a solution of sodium tellurite, which had been previously boiled. The precipitate was allowed to stand unoxidized for a week, after which it was treated for two weeks with a current of air, as in the previous case. The color changed to brown. A determination of the active oxygen indicated that about 20% of the manganese had been oxidized.

Another sample of the precipitated manganese tellurite was dried, pulverized, and left in contact with air for three weeks. At the end of this time about 38% of the manganese was oxidized, and the powder had the following composition: $3\text{Mn}_2\text{O}_3 \cdot 10\text{MnO} \cdot 16\text{TeO}_2 \cdot 10\text{H}_2\text{O}$.

	Found	Calculated for $3\text{Mn}_2\text{O}_3.10\text{MnO}.16\text{TeO}_3.10\text{H}_2\text{O}$.
Mn %.....	22.26	22.46
Te %.....	52.39	52.11
O (active)%.....	1.24	1.22
H ₂ O%.....	(4.49) estim'd	4.59

It is probable that complete oxidation of the manganese would be accomplished in time.

LEAD TELLURITE

This compound was prepared by precipitation from a solution of lead nitrate. It forms as a white flocculent precipitate. The method of analysis was exactly the same as that used in the analysis of the alkaline tellurites, namely, volatilizing the tellurium in hydrochloric acid gas, and weighing the lead as chloride. The precipitate had the composition $3\text{PbTeO}_3.2\text{H}_2\text{O}$.

	Found.	Calculated for $3\text{PbTeO}_3.2\text{H}_2\text{O}$.
Pb %.....	52.09	52.45
Te %.....	32.26	32.35
H ₂ O %.....	3.20	3.04

OXIDATION OF THE TELLURITES

Shortly after the work on the tellurites was undertaken it was discovered that many of the tellurites oxidize when heated in the air under certain conditions. This fact seemed to have escaped the notice of Berzelius and other investigators, as no mention of it has been found in the literature. On account of this oxidation it is not possible to prepare the tellurites, free from tellurates, by the fusion of tellurium dioxide with carbon-

ates, as suggested by Berzelius, without first excluding air from the mixture. Hence, in the preparation of the alkaline tellurites, the fusion was carried out in an atmosphere of carbon dioxide, as already mentioned. Tellurites which are thus prepared, when boiled with hydrochloric acid, will not liberate chlorine. But when the precaution to exclude air during the fusion is neglected, the product always has the power to oxidize hydrochloric acid to a greater or less extent. This property was used to determine the extent of the oxidation.

In order to ascertain how far it is possible to oxidize the tellurites by heating in the air, the following experiment was carried out. Some potassium tellurite was finely pulverized, and then spread out in a thin layer on the bottom of a crucible. The crucible was partly immersed in a bath of melted lead whose temperature was kept at 460° – 470° . At intervals, portions of the material were removed for analysis. The proportion of tellurate was determined by boiling the mixture with hydrochloric acid, distilling the chlorine into a solution of potassium iodide, and titrating the iodine with sodium thiosulphate. The results are given in the following table, which gives the time of heating together with the corresponding amount of potassium tellurate.

Time (in hours).	K_2TeO_4 (%).
10	26.88
20	52.88
30	80.99
38	94.49
43	97.86
57	99.47

The final product was next analyzed and the results compared with the calculated composition of anhydrous potassium tellurite and tellurate.

	Found.	K_2TeO_3 .	K_2TeO_4 .
K %	29.11	30.84	29.01
Te%	47.02	50.25	47.28

The progress of this oxidation is also represented by a curve, Fig. 2. The aim of this experiment was not to determine the "speed of reaction," although there is no doubt that the curve does represent the actual rate of oxidation in this particular case and under the existing conditions. The object here was merely to follow the course of the reaction and to find its end. The form of the curve shows plainly two things. (1) The product of the oxidation is the normal tellurate, K_2TeO_4 , and the oxidation does not go beyond this point. (2) The transformation to tellurate is complete.

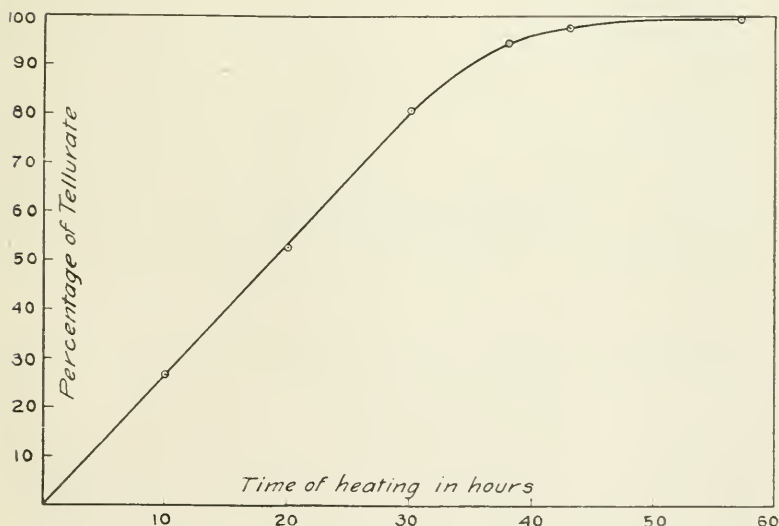


FIG. 2.

In this connection it is interesting to note that when potassium tellurate is heated to redness, it loses oxygen and is reduced to tellurite. Thus between 450° and red heat we have a reversal of the reaction



Normal sodium tellurite behaves in a manner exactly similar to the potassium tellurite, as is shown by the following table, and the curve shown in Fig. 3.

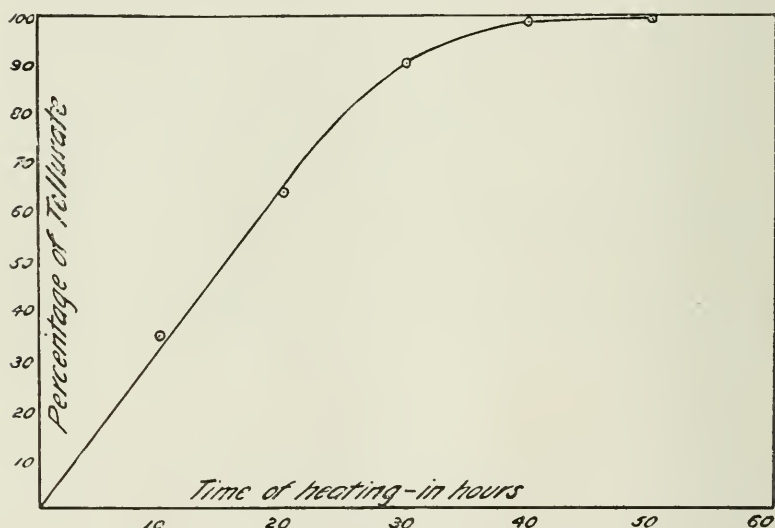


FIG. 3. Oxidation of $Na_2 TeO_3$ to $Na_2 TeO_4$.

Time of heating (in hours).	$Na_2 TeO_4$ (%)
10.....	35.09
20.....	64.77
30.....	90.76
40.....	99.09
50.....	99.49

While the normal alkaline tellurites can be oxidized quite readily, the ditellurites behave somewhat differently. Potassium ditellurite can be oxidized, but the reaction proceeds much more slowly than in the case of the normal salt. Furthermore, only one-half of the tellurium seems to be oxidizable to the higher state of oxidation. The experiment was carried out in the same way as with the normal tellurites except that the temperature was kept at 440° – 450° , on account of the lower melting point of the ditellurite. The results obtained were as follows:

Time of heating (in hours).	Active O (%).
19	1.18
46	2.00
89	2.81
156	3.28
221	3.54

The content of active oxygen required by the formula $K_2O \cdot TeO_3$, TeO_2 is 3.72%, and that for complete conversion to ditellurate would be 7.18%. It will be seen that the content of active oxygen seems to approach the former figure as a limit. This will be better seen from the curve in Fig. 4, in which horizontal distances represent the time of heating in hours, and vertical distances the percentage of active oxygen in the salt. Horizontal lines are drawn across the diagram at those points where the percentage of active oxygen would indicate the compositions $K_2O \cdot 2TeO_3$ and $K_2O \cdot TeO_3 \cdot TeO_2$.

The ditellurite of potassium is white, but when it is oxidized as above, it is slightly brown in color. This brown product belongs to a class of bodies which are formed as intermediate products in the oxidation of tellurium dioxide to trioxide, by means of alkaline oxidizing agents. These bodies Berzelius thought to be tetratellurates, but they have been shown by the work of Lenher and Potter¹¹ to have a more complex, as well as variable composition. Their composition might be represented by the

¹¹ *Jr. Am. Chem. Soc.*, **31**: 24, -1909.

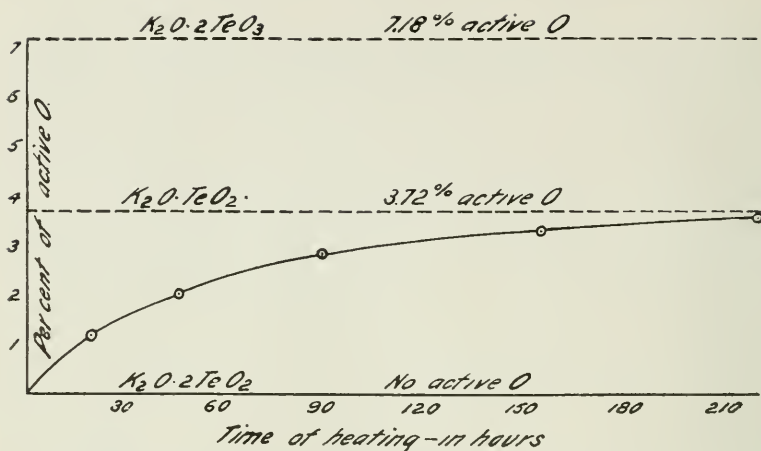


FIG. 4. Oxidation of $K_2O \cdot 2TeO_2$ to $K_2O \cdot TeO_3 \cdot TeO_2$.

general formula $m(K_2O) \cdot n(TeO_3) \cdot p(TeO_2)$, in which m , n , and p may be all different or all alike. These substances have been obtained by fusing tellurium dioxide with potassium nitrate or chlorate, and also synthetically by heating the dioxide with potassium tellurate. In the oxidation of the ditellurite of potassium to $K_2O \cdot TeO_3 \cdot TeO_2$, as described above, we are merely approaching the same class of bodies from another direction. In this case, however, the composition is simpler and more definite.

Sodium ditellurite was also heated in the same way as the corresponding potassium salt, but after five days of heating it showed only a slight trace of oxidation. Neither the tetra-tellurites nor pure tellurium dioxide show any oxidation under similar treatment. Thus we see that with a higher content of tellurium dioxide the power to take up oxygen from the air decreases.

The normal tellurites of most of the other metals, with the exception of silver, can also be oxidized, but the rate of oxidation is very much lower than in the case of the normal tellurites of the alkali metals.

It has been stated, in describing the methods of analysis, that water was usually determined by loss of weight on heating.

In view of the fact that the tellurites take up oxygen on heating, it would seem that this method of determining water would give low results. But, excepting the normal alkaline tellurites, the oxidation is so slow that the error arising from this source would be imperceptible. Thus when anhydrous magnesium tellurite is heated to 450° for fifteen hours, the gain in weight due to oxidation is only 0.25%, and in 77 hours it is only 1.5%. The content of tellurate in this second case, as shown by an iodometric determination, is only 19.3%. Again, nickel tellurite after being heated at 450° for 70 hours, contained only 0.46% of active oxygen. In contrast with these long periods of heating, the length of time necessary to drive off all the water, for the purpose of quantitative determination, is only fifteen minutes.

SUMMARY

1. The tellurites of the following have been studied: potassium, sodium, barium, magnesium, cadmium, silver, nickel, cobalt, manganese, lead, and ammonium.

2. The tellurites in general can be prepared by fusing together tellurium dioxide and a metallic oxide, hydroxide or carbonate. Since, however, tellurous acid forms salts of different degrees of saturation, namely, the mono-, di-, and tetratellurites, the above materials must be used in definite proportions in order to obtain a tellurite of definite composition. This method of preparation does not throw much light upon the composition of the tellurites, and hence these compounds were obtained by precipitation from a solution of sodium tellurite by means of a metallic salt.

3. The alkaline tellurites are soluble, the alkaline earth tellurites are slightly soluble, and those of the heavy metals are insoluble.

4. As a class, the tellurites are unstable compounds. Tellurous acid is easily displaced at ordinary temperatures in presence of moisture, by carbon dioxide.

5. The tellurites can be oxidized by heating in the air at a temperature of 440° – 470° . This oxidation is fairly rapid in the case of the normal alkaline tellurites.

6. The tellurites of most of the metals other than potassium and sodium, as well as the ditellurites of the alkali metals, will oxidize much more slowly than the normal alkaline tellurites.

7. In potassium ditellurite, only one-half of the tellurous acid is oxidizable by this means, forming the compound $K_2O \cdot TeO_3 \cdot TeO_2$. The tetratellurites are not oxidizable by heating in the air at 450° , neither is pure tellurium dioxide.

8. Manganous tellurite will oxidize on contact with the air at the ordinary temperature, but in this case the manganese is oxidized, passing to the trivalent state.

9. Ammonium tellurite probably exists in solution, and also in the solid state when surrounded by a saturated solution of tellurous acid in ammonia, but otherwise decomposes spontaneously at the ordinary temperature, forming hydrated tellurium dioxide.

10. Silver tellurite can be obtained in a number of different varieties. When precipitated in presence of an excess of sodium tellurite, it is white, but when silver nitrate is in excess, the precipitate is of a pale yellow color. This second form in the course of a few days turns to a bluish-gray powder, while the first is stable. At 250° both turn to a deep purplish-blue color. Still another variety can be obtained, by crystallizing from an ammoniacal solution, as a deep brownish-yellow substance. All of these forms are anhydrous.

11. The precipitated tellurites are all flocculent and amorphous, and with the exception of the magnesium salt, show practically no tendency to become crystalline.

12. These precipitates are very apt to occlude other salts as impurities, which are very difficult to remove. This tendency is most marked in the barium salt, which will occlude enormous quantities of barium chloride. In the case of lead tellurite, which was precipitated from a solution of lead nitrate, the precipitate contained nitrates, but these were not so difficult to remove as the chlorides.

13. With the exception of the silver salt, these precipitates are all definite hydrates, which do not readily give up their water.

In conclusion, the author wishes to make acknowledgment of

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